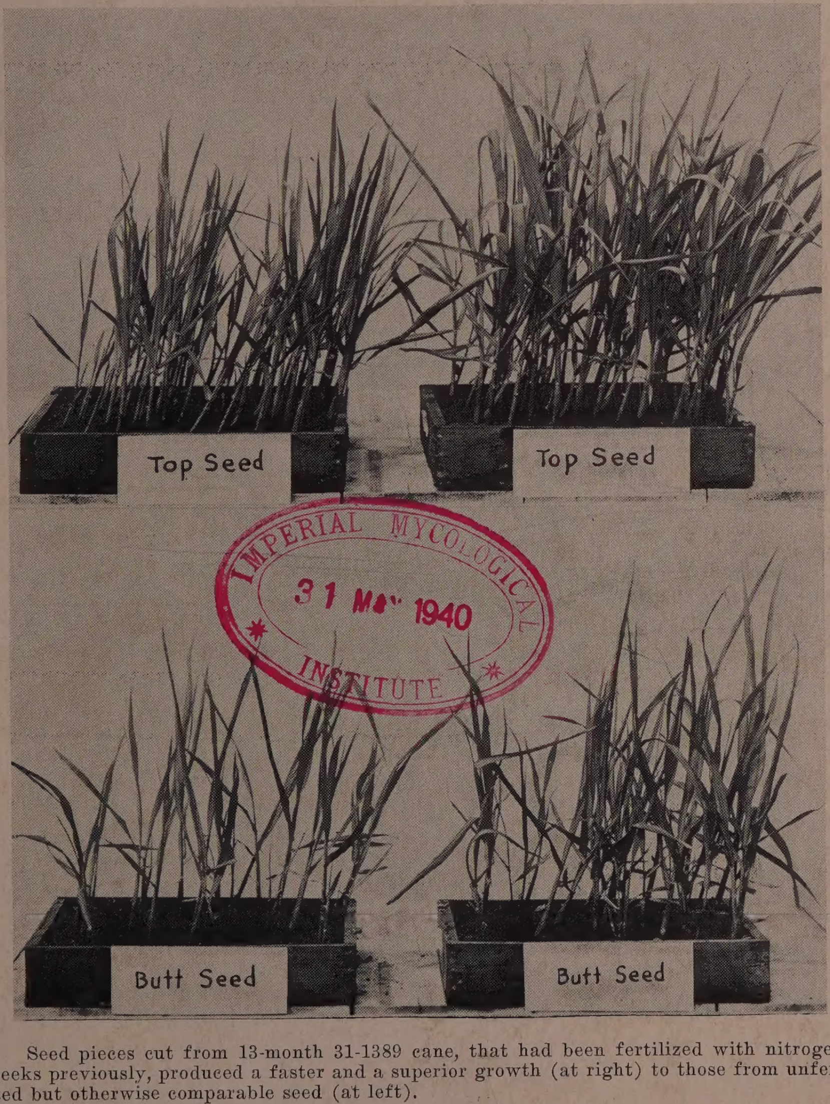
VOLUME XLIV NUMBER 1

THE HAWAIIAN PLANTERS' RECORD



IMPERIAL MYCOLOGICAL INSTITUTE
31 MAY 1940

Seed pieces cut from 13-month 31-1389 cane, that had been fertilized with nitrogen 2 weeks previously, produced a faster and a superior growth (at right) to those from unfertilized but otherwise comparable seed (at left).

FIRST QUARTER 1940

COPYRIGHT 1940 BY HAWAIIAN SUGAR PLANTERS' ASSOCIATION

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

OFFICERS FOR 1940

R. A. COOKE . . . . President
H. A. WALKER . . . . 1st Vice-President
A. G. BUDGE . . . . 2nd Vice-President
B. H. WELLS . . . . Executive Vice-President and Secretary
E. W. GREENE . . . . Vice-President
S. O. HALLS . . . . Treasurer and Assistant Secretary
W. PFLUEGER . . . . Assistant Treasurer
C. B. WIGHTMAN . . . . Assistant Secretary
G. E. SCHAEFER . . . . Auditor

TRUSTEES FOR 1940

R. A. COOKE
H. A. WALKER
A. G. BUDGE
J. E. RUSSELL
JOHN WATERHOUSE
G. E. SCHAEFER

EXPERIMENT STATION COMMITTEE

L. D. LARSEN, Chairman

H. P. AGEE
W. VAN H. DUKER
A. L. DEAN
W. W. G. MOIR
G. E. SCHAEFER
D. BOND

A. R. GRAMMER, Secretary

Advertiser Publishing Co., Ltd.
Honolulu, Hawaii, U.S.A.

THE HAWAIIAN PLANTERS' RECORD
Vol. XLIV FIRST QUARTER 1940 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Field Movement of Sugar Cane Beetle Borer Adults:

By marking adults of the sugar cane beetle borer, and later recovering them in traps, it was found that Rhabdocnemis beetles travel considerable distances by flight, and are directly influenced in such movement by winds. Marked beetles were recovered which show that they can survive in the field for long periods, up to six months. Infestation of a cane field is begun by beetles entering the field from adjacent areas, and is not continued from crop to crop by beetles bred in that particular field.

Some Effects Produced on Sugar Cane by Minor Elements:

The application of a rather complete mixture of the "minor elements" to a wide range of soil types has indicated some quite different effects upon cane composition and yields from such soils.

Border Effect in Field Experiments that are Concerned with Fertilizer Practices:

Although differences of opinion are prevalent regarding the extent of the actual error that may be introduced into fertilizer experiments by "border effect," it may be safer to eliminate or to reduce such a source of error than to overlook its possible effect. Several practical measures which are available for doing this are suggested.

Proper Proportioning and Timing of Nitrogen Applications:

Evidence is presented which indicates that the proper proportioning and timing of the total nitrogen application for a sugar cane crop have made for greater efficiency in the use of nitrogen fertilizers.

A Chytrid in Relation to Chlorotic Streak Disease of Sugar Cane:

An intracellular parasite of sugar cane, apparently unrecorded, was observed in a survey of organisms associated with chlorotic streak diseased cane. This parasite, a primitive fungus of the aquatic type known as Chytrids, was found within the cells of the stalks, buds and leaves of affected cane. Since the article was submitted an apparently identical organism has been observed in elephant grass (*Pennisetum purpureum*) bearing streak lesions typical of the disease in cane. Among the Chytrids are notorious parasites of economic plants such as *Urophylyctis alfalfae* (root gall of alfalfa), *Physoderma zeae maydis* (leaf and stalk disease of corn), *Synchytrium endobioticum* (wart disease of the potato), and *Olpidium brassicae* (root parasite of cabbage).

The Chytrid is of interest as a possible cause of chlorotic streak disease which in wet locations probably occurs much more commonly in symptomless form than is generally realized. This novel parasite is possibly more significant as an insidious invader of cane in such environments where it may contribute to subnormal germination, growth depression and deterioration of maturing cane. The observations are discussed as an introduction to the etiology of the perplexing chlorotic streak disease.

Analysis of Agricultural Materials by the Spectrograph:

The analytical chemist has at his disposal a new tool, the spectrograph. The fundamental principles of so-called "spectrochemical analysis," and the experimental methods used in analyzing materials by the spectrograph are described. A discussion of its particular advantages and limitations in qualitative and quantitative analysis is given.

Many different types of materials can be analyzed by the spectrograph. Examples are given of the determination of the mineral composition of such varied substances as sugar cane, insects, raw sugar composites and fertilizers. These are a few cases drawn from the three years' accumulation of data in the spectroscopic laboratory of the Experiment Station.

Irrigation Interval Control as an Aid in Lowering Production Costs:

Results from an experiment in cooperation with Waialua Agricultural Company, Ltd., indicate that savings in the cost of sugar production under irrigated conditions may be affected by permitting the plant to grow under conditions of soil moisture deficiencies for a short time prior to each irrigation. The cane plants kept in full vegetative vigor during the life of the crop produced a ton of sugar with an investment of $13.90 in irrigation water and irrigation labor. When eight days of depressed vegetative growth were introduced prior to each application of water the irrigation costs were $8.30 per ton of sugar. Both treatments produced the same number of tons of sugar per acre.

Some suggestions are made with respect to the future work which is necessary for the correct understanding of the factors involved in this important relationship.

Field Movement of Sugar Cane Beetle Borer Adults

By R. H. Van Zwaluwenburg and J. S. Rosa

Earlier work at Kailua (*The Hawaiian Planters' Record,* 52: 167-173, 1938) indicated that there is a constant movement of *Rhabdocnemis obscura* beetles to and from cane fields, and that such movement is more marked when cane is being harvested. Movement of beetles in the field is probably largely by flight rather than along the ground, for beetles which have dropped to the ground soon either hide under convenient cover or climb onto nearby plants. In order to obtain information concerning the distance and rate of adult borer movement, the influence of prevailing winds, etc., an experiment, conducted by the writers in Fields L-M-P, Kailua, was begun in February 1939, and continued for a year.

Beetles were collected each month in split-cane traps, given a small dab of a distinguishing color, and released at a fixed station. Quick-drying lacquers and aluminum paint were equally satisfactory, but bronze paint did not long survive field conditions. Split-cane traps for the recovery of marked beetles were installed monthly at twenty fixed stations and were examined about every two weeks. Thus it was possible to determine, roughly, the distance which recaptured beetles had traveled, and the time that had elapsed since their release.

There were trapped, painted and released 19,225 beetles; 10,726 (55.7 per cent) were males, and 8,499, females. One hundred fifty males (1.39 per cent of those released) were recovered, and 96 females (1.12 per cent). Split-cane traps attract beetles for probably only a few feet, at most, so recovery of painted individuals at widely scattered traps (there was one trap for about every two acres) was largely a matter of chance. Of all the beetles released, 1.29 per cent were recovered.

The greatest distance a marked beetle was known to travel was about 1670 feet; this was an individual of unknown sex, observed by R. Urata of the Genetics department in Field K, 85 days after its release. Several recoveries were made at distances greater than 1000 feet, the farthest being a male recaptured 1240 feet away after 82 days. Glick (U.S.D.A. Tech. Bull. 673, 1939) records from Texas the trapping of various beetles by airplane at heights up to 6000 feet. None of the beetles he records is as large as Rhabdocnemis, but the fact that even small beetles fly, or are carried by air currents, to such altitudes, makes it likely that beetle borer adults too, are sometimes swept to considerable heights by strong winds, and in that way travel distances greater than any recorded here.

The following table summarizes the recaptures of marked beetles at Kailua:

RECOVERIES OF PAINTED RHABDOCNEMIS BEETLES WITH REFERENCE TO PREVAILING WINDS

Approximate distance: feet	Painted beetles recovered: Total	Males	Females	Sex unknown	Days between release and recapture: Maximum–Minimum	Average
South-Southwest (down-wind)						
305	72	37	35		6–111	24 days
365	50	32	17	1	13–176	46 "
620	11	5	6		13– 97	41 "
695	11	8	3		13– 97	45 "
740	1	1	0		41	41 "
805	16	7	9		13– 97	53 "
825	4	3	1		13– 41	24 "
985	0	0	0		....	....
1050	3	2	0	1	18– 69	38 "
1210	2	1	1		41– 69	55 "
1240	1	1	0		82	82 "
1245 (Fld. K) ..	0	0	0		....	....
Total	171	97	72	2		
North-Northeast (up-wind)						
265	30	22	8		13–163	52 "
300	10	5	5		13–110	49.5 "
405	30	20	9	1	13–167	47 "
600	3	2	1		41–154	97 "
740	4	3	1		27–127	69 "
825	1	1	0		70	70 "
1240	0	0	0		....	....
1480	0	0	0		....	....
Total	78	53	24	1		

In considering this table, as well as the following one, it should be remembered that the figures for distances and elapsed time are by no means exact. Recovery traps were examined about every two weeks; the distances are only minimum, or apparent, for some beetles may have traveled considerably farther than indicated. Progress is probably aimless and indirect, being effected by short, erratic flights; one male was recovered at a down-wind trap, 1050 feet away, after 18 days, while another took not less than 140 days to reach an up-wind trap only 265 feet away.

Beetles apparently took less time to travel down-wind, and moved farther in that direction than up-wind. The average distances at which beetles were recovered, and the average time between their release and recovery, were as follows:

	Distance	Time elapsed between release and recovery
Up-wind		
Males	370 $\mp$ 19.5 feet	54.5 $\mp$ 4.9 days
Females	365 $\mp$ 9.9 "	41.7 $\mp$ 3.1 "
Down-wind		
Males	465 $\mp$ 21.3 feet	37.9 $\mp$ 3.5 days
Females	447 $\mp$ 28.4 "	29.9 $\mp$ 2.9 "

There is no statistically significant difference* in directional trend between the sexes, but the movement of both males and females down-wind, as compared with up-wind, is strongly significant. The differences between up-wind and down-wind figures for distance and rate of movement, also are significant when data for the same sex are compared. The differences between males and females moving in the same direction (down-wind or up-wind) are not significant.

The discrepancy between numbers recovered at the 740-foot trap and at the one 805 feet from the release station, is striking. The two were situated as follows: The 740-foot trap was diagonally down-wind, well within a field of old cane. The other was in young cane about shoulder-high at the start of the experiment, with the rows running almost directly down-wind in the direction of the trap; only one painted beetle was recovered at the 805-foot trap after September.

It is not certain that wind is the only factor influencing the flight of beetles, but we believe it is the most important. This opinion is based upon field tests. In a total absence of breeze, 34 Rhabdocnemis adults were released at two stations from a straight-sided jar about seven feet above ground. They flew in all directions, usually in long, erratic, more or less horizontal loops tending earthward; one or two had risen to a height of about 30 feet when they disappeared in the distance. Another lot of 49 beetles was similarly released in a very light breeze; 45 took off and flew directly down-wind, while four flew across-wind; most of them flew heavily, but more directly than those in no breeze, and a few flew high at considerable speed on a nearly straight course. Neither lot seemed influenced by the nearness or absence of cane. It therefore seems certain that even light winds influence directly the field movement of flying beetles, and it is probable that heavy winds carry them long distances. Under a bright sun the beetles were more active and took flight more readily than when the sky was overcast. Among the beetles used in these tests was a painted male which had been recovered 176 days after release; it flew as easily as the unpainted ones.

The larger number of recoveries down-wind, and the more extended and more rapid progress in that direction, may be partly because all the beetles were released on the edge of a fairly old stand of cane with an open area in taro immediately south of it. Beetles would find flying easier across this open space than through the dense cane growth to the northward.

Another factor perhaps favoring movement of flying beetles down-wind was the small size, at the start of the experiment, of the young cane across the taro patch, about 75 yards south of the release station. Beetles rising six to ten feet above ground would, in that direction, meet no obstacle to interrupt their flight, as they would at the same low elevation in taller cane. It may be significant that the percentage of recovered beetles became generally less as the year advanced, and as the cane grew taller.

The recapture of a male beetle 176 days after being painted and released, substantiates Koebele's surmise that the adult cane borer is very long-lived, surviving possibly as long as a year under field conditions. It is not known how old this beetle was when first captured and painted.

---

* All results were examined for statistical significance by R. J. Borden and L. R. Smith of the Agricultural department.

Movement of adult borer beetles into newly planted areas is mainly responsible for beginning infestation there; and it appears to be the first step in the infestation of ratoon fields as well. This conclusion is based upon observations made in Field ADA, Kailua, during the twelve months following harvest in February 1939. Immediately after the cane was cut, 3.7 per cent of the stubble was found to contain living borer grubs. During the next five months occasional beetles were found on the ratooning plants, but it was not until the sixth month that oviposition and infestation had begun. By the sixth month cane had begun to form; previously, as long as the stalks consisted only of sheaths and leaf material, no egg laying took place. All the grubs left in the stubble after harvest had certainly developed into beetles by the second or third month; as adults therefore, they either remained two months or longer in the field awaiting the formation of cane suitable for egg laying, or, as is more probable, moved off elsewhere to older cane. Therefore most, if not all, of the infestation of the ratoon cane began from eggs laid by beetles which came into ADA from outside fields. So, clearing a field of infested stalks after harvest is important, not because of the immediate infestation of the subsequent ratoon, but because infested material serves as a source of infestation for nearby cane.

Conclusions

1. Adult Rhabdocnemis beetles move (mainly by flight) considerable distances, to a known maximum of about one-third of a mile. Winds are probably the main influence affecting their field movement. In the absence of air currents beetles fly in any direction, but even light winds appear to influence the direction, extent and rate of their movement; heavy winds probably carry them long distances.

2. Adult borer beetles can survive in the field for 176 days, or 25 weeks, and may live even longer.

3. Borer damage to each crop of cane in a given field is independent of the preceding infestation in the same field. Infestation is begun by beetles coming into the field from adjacent fields, and is not continued from crop to crop by beetles bred in that particular area. Infestation begins only after the plants have formed cane; at Kailua this occurred in ratoon cane between five and six months of age.

Some Effects Produced on Sugar Cane by Minor Elements

By R. J. Borden

When the growth of cane is subnormal and the reason is not easily apparent, we have formed a habit of applying the term "growth failure" to such a condition. In an exploratory attempt* to find whether this poor cane growth might be due to some deficiency of the so-called "minor elements" in the soil, a collection of soils was secured from widely scattered areas where unsatisfactory cane growth had been observed. The identity of the soils which were studied and the results of the "R.C.M." analyses for their major available nutrients is given in Table I.

The soil samples were thoroughly prepared and potted, and planted with pre-germinated shoots of the variety H 109 in July, 1938. At the time of planting, 6 pots of each soil were uniformly and adequately fertilized with N, P_2O_5, and K_2O, from ammonium nitrate, superphosphate, and sulphate of potash. In addition, 3 pots of each soil were supplied with a generous allowance of a mixture of chemicals which has been termed our "A to Z"† mixture of minor elements. The composition of this mixture as made up by our Chemistry Department was as follows:

41.25	parts of	calcium sulphate
12.50	" "	ferrous sulphate
4.50	" "	copper oxide
.50	" "	copper sulphate
2.50	" "	boric acid
2.25	" "	zinc oxide
.25	" "	zinc sulphate
5.00	" "	manganese dioxide
1.25	" "	manganous sulphate
5.00	" "	magnesium sulphate
25.00	" "	magnesium silicate

Similar applications of this mineral mixture were again made at 4, 6, and 8 months, at the same time that additional applications of nitrogen and potash were given to all pots. Growing conditions were uniformly maintained, with adequate irrigation being furnished throughout the growing period. The crop was harvested at the age of 12 months, and the juice, as obtained from the millable cane crushed in our small 3-roller mill, analyzed for several constituents.

Observations and growth measurements, which had been made between March and July, 1939, had failed to show any reliable differences between the paired treatments on any of the soils. The results at harvest did, however, show up several

* Project A-105—No. 124.

† This term is credited to Dr. D. R. Hoagland, who used an "A to Z" nutrient solution in his studies in California.

differences which statistical analysis indicate are not likely the effects of chance. These can be observed by inspecting the data in Table II, which summarize the measurements made. Or we may ~~comment briefly~~, that the "A to Z" mixture of minor mineral elements may* have had the following specific effects on the cane which was grown on the different soils used in this study:

Soil No.	Source	Effect of "A to Z"
1	Manoa No. 37..............	Decreased N and K_2O in juice
3	Kailua (kula)	Increased K_2O in juice
5	Kailua (bottom)	Increased K_2O in juice; increased sugar
7	Waipio (Yamada)	Increased P_2O_5 in juice; increased cane and sugar
9	Kahuku—No. 4 (poor)......	Increased K_2O in juice
11	Kahuku—No. 4 (good)......	No significant effects
13	Ewa No. 9A	Decreased P_2O_5 and K_2O in juice; increased sugar
15	Ewa No. B	Decreased K_2O in juice
17	Ewa No. 19D	Increased N, P_2O_5, and K_2O in juice
19	Libby No. 134..............	Decreased N and increased K_2O in juice; increased cane, improved quality, and increased sugar
21	Grove Farm Co. 31C.........	Decreased K_2O in juice
23	Kilauea No. 28D............	No significant effects
25	Kauai Variety Station.......	No significant effects
27	Hawaiian Sugar No. A1D....	No significant effects
29	H. C. & S. Co. No. 8........	Decreased P_2O_5 and K_2O
31	Hamakua Variety Station....	No significant effects
33	Hamakua—No. 27K	Decreased K_2O in juice
35	Hamakua—No. 32K	Increased K_2O in juice
37	Hawn. Agr. M–M–2–1	Decreased cane and sugar
39	Hawn. Agr. Hio. 23	Decreased cane and sugar
41	Onomea—No. 64	Decreased N and increased K_2O in juice
43	Pepeekea—No. 38	No significant effects
45	Kohala—No. Ho. 7A........	Decreased P_2O_5 in juice; increased cane and sugar

It is immediately apparent that these effects which have been produced upon sugar cane by supplying these minor elements to the soil have been quite different on the different soils. We shall make no attempt at this early stage in our studies to offer explanation for such differences, our objective herein being simply to present the results as we have secured them, with the thought that further research may be undertaken in connection with possible minor element deficiencies. It is now necessary to see if these results can be duplicated, and then to break down the "A to Z" mixture to determine the dominant factor or mineral which is responsible for the specific effects observed.

---

* The effect would not be expected by chance more often than once in 20 times.

TABLE I

IDENTITIES OF SOILS USED

Soil No.	Source	Available nutrients p.p.m. N	Available nutrients p.p.m. P_2O_5	Available nutrients p.p.m. K_2O	pH	P_2O_5 fixation index
1	Manoa 37	8	6	28	4.6	90
3	Kailua—kula land	15	4	50	4.6	75
5	Kailua—bottom land	16	240	50	6.2	55
7	Waipio—Yamada	20	320+	310	6.9	35
9	Kahuku 4 (poor)	50	320+	120	6.6	50
11	Kahuku 4 (good)	23	320+	120	7.0	40
13	Ewa 19A	14	200	90	6.9	45
15	Ewa B	16	40	120	6.9	45
17	Ewa 19D	8	40	90	6.8	65
19	Libby 134	16	2	19	5.6	90
21	Grove Farm 31C	43	40	— 30	5.8	65
23	Kilauea 28D	14	60	40	7.1	60
25	Kauai Variety Station	8	6	40	6.2	85
27	Hawaiian Sugar A1D	16	40	70	5.0	90
29	H. C. & S. Co. 8	7	80	140	7.2	60
31	Hamakua Variety Station	15	120	— 30	4.8	90
33	Hamakua 27K	20	80	28	4.9	90
35	Hamakua 32K	16	40	— 30	4.7	90
37	Hawaiian Agricultural M–M–2–1	26	240	— 30	4.7	90
39	Hawaiian Agricultural Hio. 23	18	120	— 30	4.8	80
41	Onomea 64	28	60	28	4.9	90
43	Pepeekeo 38	37	40	— 30	5.0	90
45	Kohala 7A	24	100	120	6.6	55

TABLE II

SUMMARY OF YIELDS

(Averages of 3 Pots)

Soil No.	Treatment	Wt. of cane in gms.	Q.R.	Y%C	Wt. of sugar in gms.	% N in juice	% P_2O_5 in juice	% K_2O in juice	Total dry wt. (gms.)
1	CK	1694	7.2	13.83	234	.068*	.006	.030*	903
	A–Z	1697	7.6	13.23	225	.051	.006	.010	930
3	CK	2011	7.1	14.15	285	.060	.006	.013	1086
	A–Z	1944	6.9	14.42	280	.066	.006	.023*	1096
5	CK	2108	7.0	14.30	301	.025*	.006	.023	1198
	A–Z	2255	6.7	15.01	338*	.016	.006	.030*	1230
7	CK	1640	6.7	15.01	247	.025	.010	.050	1067
	A–Z	1860*	6.8	14.78	275*	.029	.012*	.053	1118*
9	CK	2298	6.6	15.24	350	.018	.011	.030	1335
	A–Z	2386	6.8	14.73	352	.013	.012	.037*	1360
11	CK	2216	6.9	14.50	321	.013	.016	.030	1274
	A–Z	2247	6.7	14.86	334	.017	.017	.030	1280

* Significantly different.

Soil No.	Treatment	Wt. of cane in gms.	Q.R.	Y%C	Wt. of sugar in gms.	% N in juice	% P_2O_5 in juice	% K_2O in juice	Total dry wt. (gms.)
13	CK	1883	6.7	14.88	282	.029	.009+	.043*	1073
	A–Z	2042	6.5	15.31	313*	.031	.007	.033	1143*
15	CK	1871	6.9	14.44	271	.024	.007	.043*	1111*
	A–Z	1806	7.1	14.03	253	.022	.007	.037	1062
17	CK	1513	6.9	14.56	220	.032	.006	.027	911
	A–Z	1564	6.9	14.50	227	.047*	.008+	.037*	931
19	CK	1226	8.1	12.30	153	.098*	.001	.037	678
	A–Z	1450*	7.2	13.80*	200*	.073	.001	.043*	785*
21	CK	2188	6.9	14.57	320	.035	.001	.027*	1186
	A–Z	2103	7.0	14.35	302	.035	.001	.020	1164
23	CK	1938	6.7	14.93	289	.028	.006	.025	1002
	A–Z	2047	6.6	15.02	307	.026	.006	.023	1158*
25	CK	1204	8.1	12.38	152	.109	.001	.050	653
	A–Z	1278	8.2	12.26	157	.103	.001	.047	765*
27	CK	1650	7.2	13.89	229	.075	.001	.043	962
	A–Z	1702	7.1	13.99	238	.078	.001	.045	894*
29	CK	1964	6.7	14.93	293	.023	.010*	.050*	1084
	A–Z	2000	6.8	14.78	295	.022	.006	.043	1053
31	CK	1833	7.2	13.90	255	.041	.005	.037	991
	A–Z	1778	7.4	13.43	240	.046	.006	.037	976
33	CK	2248	7.0	14.22	320	.053	.006	.030*	1136
	A–Z	2229	7.1	14.02	312	.050	.006	.020	1120
35	CK	1853	7.4	13.53	251	.047	.004	.030	981
	A–Z	1894	7.4	13.59	259	.046	.003	.037*	1021
37	CK	2885*	7.3	13.70	395*	.026	.004	.013	1450*
	A–Z	2620	7.2	13.97	366	.029	.004	.017	1358
39	CK	2570*	6.9	14.50	373*	.034	.003	.013	1331*
	A–Z	2411	7.0	14.30	344	.040	.003	.017	1255
41	CK	2032	6.9	14.57	296	.033*	.004	.017	1139
	A–Z	2113	7.3	13.73	290	.020	.003	.033*	1150
43	CK	2547	7.1	14.15	361	.027	.004	.010	1282
	A–Z	2633	6.9	14.50	382	.025	.004	.010	1321
45	CK	1764	6.9	14.43	255	.017	.013*	.050	1128
	A–Z	2106*	6.7	14.94	315*	.021	.010	.050	1253*
Amount of difference needed for significance (by analysis of variance)		164		1.15	26	.008	.001	.005	45

Treatments: CK—Fertilization with N, P, K only.
A–Z—Fertilization with N, P, K and "A–Z" mixture.

* Significantly different.

Border Effect in Field Experiments that are Concerned with Fertilizer Practices

By R. J. Borden

Some concern has been felt over the possible influence of border effect between differentially fertilized plots in the recently proposed complex experiments (factorial arrangements).

In the simple experiments, we have advocated the use of a balanced arrangement of the treatments in which a minimum treatment difference occurs between adjacent plots, i.e., the low amount and the high amount are not placed in adjacent plots; for example:

A	B	C	C	B	A	A	B	C	C	
75# N	125# N	175# N	175# N	125# N	75# N	75# N	125# N	175# N	175# N	etc.

Through the use of this arrangement, we believe that border effect has been greatly reduced in those simple tests which have but a single objective; also, that our balanced distribution is less apt to have a systematic error from such fertility slopes as exist in our cane lands.

In the complex experiments, especially where the 2 x 3 Block or the 3 x 3 Graeco-Latin Square arrangement is used, it is not always possible to have a balanced plan and at the same time avoid having the low and the high amount in adjacent plots. For instance, a very good 2 x 3 Block arrangement for 6 combined treatments would be this one:

A1	X3	A3	X2	A2	X1
X2	A2	X1	A1	X3	A3
A3	X1	A2	X3	A1	X2
X1	A3	X3	A2	X2	A1
A2	X2	A1	X1	A3	X3
X3	A1	X2	A3	X1	A2

Here, if "A" and "X" are two levels of phosphate, and "1," "2," and "3" are respectively low, medium, and high levels of nitrogen, there are many instances wherein the low and the high nitrogen levels are in adjacent plots. It is in such cases that we are most concerned about border effects.

Actual data from fertilizer tests with sugar cane in Hawaii that can be studied to find the actual extent of border effect are lacking. The 13th consecutive crop

from Waipio Expt. V in 1936 was harvested line by line in order to find possible evidence of border effect between 18 pairs of "N" vs. "NPK" plots from a checkerboard arrangement. The results indicated no reliable differences between these two treatments, and failed to furnish evidence that border effect was a factor in this particular instance. This may be seen from the following:

Plot size	Lines discarded	Avg. TCA difference favoring NPK over N	Student's odds
All 8 lines	None	2.1	8 to 1
6 center lines	1 outer line on each side	2.2	8 to 1
4 center lines	2 outer lines on each side	2.4	12 to 1
2 center lines	3 outer lines on each side	2.3	4 to 1
2 outside lines	4 center lines	1.9	4 to 1

Hence until such time as reliable data can be secured, we need to argue the case on the basis of certain assumptions.

Border effect in field tests with sugar cane is chiefly the result of availability of nutrients and of shading. When due to nutrients, those rows where the nutrient supply has been insufficient may benefit by securing food from the adjacent row where the nutrient was more adequately supplied; this may result in the outside rows of the "low-level" plot having a higher yield than the inner rows because of this extra food supply. When due to shading, the outside row, of the faster-growing plot which was adequately fertilized, tends to shade the outside adjacent row of the slower-growing plot which has an inadequate nutrient supply, thus lowering the yield of this row. Hence, these two factors may have an opposite effect which may tend to offset one another.

Granting for the moment, however, that these two opposite effects may not balance each other, we are interested in a probable maximum border effect which might cause us to misinterpret our experimental results.

We have inspected the actual T.C.A. yield differences which have been recorded in all of our cooperative "Amounts-of-Nitrogen" tests in which a minimum level was included at 100 pounds per acre or less, and which had a maximum level that was higher by 100 pounds or more than such minimum. Out of a total of 151 of such experiments, 116 or 77 per cent show a maximum T.C.A. difference between the low and the high nitrogen treatment of less than 20 per cent. Hence it would seem that we might consider that whenever a border-effect influence is operative, its maximum effect would not likely be greater than this 20 per cent yield difference. With this assumption, we may then proceed to calculate the expected error which border effect might have on the outside rows of our test plots.

For a simple but impressive example, let us take a plan in which plots receiving a low nitrogen level (A) are found adjacent to plots which receive a high nitrogen level (X), e.g.:

X	A	X	A	X	A	
175# N	75# N	175# N	75# N	175# N		etc.

Let us further assume that, *without border effect,* the "A" plots will produce an average of 70 T.C.A. and the "X" plots 84 T.C.A. (20 per cent more). With plots of one-tenth acre, each carrying 8 lines (5 ft. x 109 ft.), each line of an "A" plot would be expected to produce .875 ton of cane, and each line of an "X" plot to have 1.05 tons of cane. By allowing the "full" (20 per cent) influence of border effect to one outer line on each side of the "A" plots, such plots would then have 6 lines at .875 ton and 2 lines at 1.05 tons, or a total of 7.350 tons, which would be equivalent to 73.5 T.C.A.; this is a 5 per cent increase in cane yield which might be an error due to border effect.

If, instead of an 8-line plot, we had used 10 lines in our one-tenth-acre plot, the yield of the "A" plots would be 72.8 T.C.A.—a 4 per cent increase. And with a 12-line plot of the same area, the "A" treatment would average 72.3 T.C.A.—only 3.3 per cent increase when the assumed full value has been allowed for border effect on the outer rows.

Since it is extremely doubtful that the outer row will receive *the full benefit* from the higher nitrogen application in an adjacent row of an "X" plot, we would be inclined to greatly discount the full amounts which we have allowed above. In which case, we may be unduly concerned with a rather minor factual influence upon our experimental results.

However, if we still feel that we must do something to eliminate or to reduce border effect, and it is perhaps a safer procedure to eliminate or provide for this source of error than to be led to erroneous conclusions by overlooking it, then there are several practical measures, any of which might be adopted:

1. The use of 12, 14, or even 16 lines within a one-tenth-acre plot would result in less border effect than will be found in 8-line plots on the same area. If this necessitates the use of several tiers of plots, then border effect at the ends of the rows in each tier can be overcome by restricting the fertilizer applications to a point 5 feet from the ends of rows of those plots which are adjacent end-to-end.
2. Where the suitable area for a test is unlimited, we might increase the total size of our test area so as to provide plots that are twice the size of an area we wish to have for harvesting. Thus if we wish to have 8 lines for harvest, we could apply our fertilizer treatment to a 16-line plot and harvest the 8 center lines only. This would shape itself into a plan as follows:

4 lines	16 lines Treatment A
8 lines for harvest	
4 lines	
4 lines	16 lines Treatment X
8 lines for harvest	
4 lines	

etc.

3. Where such additional area for testing is not available, a procedure, which is actually based on the assumption that border effect does exist, is proposed in order to use such effect to our advantage. In this plan, fertilizer would be applied to the inside of the outer row of the more adequately fertilized plot, at an amount that was only equal to that applied to ~~the outer row~~ of the adjacent less adequately fertilized plot, and the remainder which was withheld would be put on the next inner row. Thus we would make the cane in each outside row of the more adequately fertilized plot draw upon its next inner row for its full allotment of plant food. In such a case, there should be but little effect of the higher level of fertilization on the adjacent cane row of the plot with the lower level. We might illustrate this plan as follows:

	etc. ↑
PLOT "A" —	row #5 at 100 lbs. N/acre on upper side of row
100 lbs.	row #6 at 100 lbs. N/acre on upper side of row
N per acre	row #7 at 100 lbs. N/acre on upper side of row
	row #8 at 100 lbs. N/acre on upper side of row
	row #1 at 100 lbs. N/acre on lower side of row (1)
	row #2 at 220 lbs. N/acre on upper side of row (2)
	row #3 at 160 lbs. N/acre on upper side of row
PLOT "B" —	row #4 at 160 lbs. N/acre on upper side of row
160 lbs.	row #5 at 160 lbs. N/acre on upper side of row
N per acre	row #6 at 160 lbs. N/acre on upper side of row
	row #7 at 160 lbs. N/acre on upper side of row
	row #8 at 160 lbs. N/acre on upper side of row
	row #1 at 160 lbs. N/acre on lower side of row (3)
PLOT "C" —	row #2 at 280 lbs. N/acre on upper side of row (4)
220 lbs.	row #3 at 220 lbs. N/acre on upper side of row
N per acre	row #4 at 220 lbs. N/acre on upper side of row
	etc. ↓

(1) Same amount as to row 8 of plot "A."
(3) Same amount as to row 8 of plot "B."
(2) 60 lbs. withheld from row 1 to be added to amount scheduled for row 2.
(4) Amount, i.e., 60 lbs., withheld from row 1 to be added to amount scheduled for row 2.

Furthermore, where plots are adjacent, end to end, we would stop the applications of fertilizer in each row of the more adequately fertilized plot at a point at least 5 feet from the ends of the rows; this should reduce the border effect at these points also.

Because of the high "separation error" which can be introduced in separating heavy tonnage cane at harvest, we are not enthusiastic about the procedure of cutting out and discarding an outside or border row when the cane stalks are badly tangled. Hence, no attempt would be made to discard these outside rows or ends at harvest, since it would be assumed that their yields would not be subnormal; and even if they might be slightly so, the yields would still be comparable, for all plots will have been similarly handled.

We believe that the factorial arrangements can and will furnish us with a better and more comprehensive technique for field tests with sugar cane, and we should not hesitate to use such arrangements, for fear of a misinterpretation of the yields therefrom, when by using these practical methods we can greatly reduce and perhaps actually eliminate the border effect.

Proper Proportioning and Timing of Nitrogen Applications

By R. J. Borden

A study* which was designed to determine the relation between the time of applying varying amounts of nitrogen fertilizer and the resulting cane and sugar yields, in connection with our controlled pot culture procedure for sugar cane, may possibly contribute information of interest to others who can see in the results from pot studies some relationships with specific field conditions where the results may find some application.

Single-eye cuttings of the variety 31–1389 were planted on November 1, 1938, in Mitscherlich pots filled with Makiki soil. Adequate phosphate and potash, and ample irrigation water were supplied. Nitrogen differentials consisted of 3 levels: (L) *low*, or an inadequate amount for good growth of cane in the small containers which we used; (M) *medium*, or an amount which our previous experience had indicated to be approximately optimum; and (H) *high*, which probably furnished a luxury supply. Each nitrogen level (total) was applied in 6 different ways: (1) all in one application at 1 month; (2) ½ at 1 month and ½ at 3 months; (3) ½ at 1 month and ½ at 5 months; (4) ¼ at 1 month and ¾ at 3 months; (5) ¼ at 1, ¼ at 3, ¼ at 5, and ¼ at 7 months; (6) ¼ at one month, ¼ at 3 months, and ½ at 7 months. The cane was harvested at 12 months and we have secured the following data which have been analyzed statistically from the plan of the 3 x 6 factorial arrangement that was used.

TABLE I

AVERAGES OF 24 PLOTS FOR EACH "LEVEL" OF NITROGEN

Level of N applied	lb cane	Y%C	lb sugar	% N in juice	Juice purity	p.p.m. available nitrogen in soil at harvest
Low	3.84	13.36	.51	.011	88.0	7
Medium	4.96	12.93	.64	.021	87.5	7
High	3.18	9.25	.34	.072	77.6	9
Difference required for significance	.26	.36	.03	.008	3.7	1

There were significant yield and quality differences between the 3 levels at which the nitrogen was supplied. It is quite apparent that too much nitrogen can be harmful to cane yields as well as to cane quality, more especially, as will be seen later, when heavy applications are made to young cane in such a way that the soluble fertilizer salt creates a highly concentrated soil solution within the root zone of young plants.

* Project A–105—No. 126.

TABLE II

AVERAGES OF 12 POTS FOR EACH "TIME OF APPLICATION"

Treatment No.	Time of applying N	lb cane	Y%C	lb sugar	% N in juice	Juice purity	p.p.m. available N in soil at harvest
1	All at 1 month................	2.99	9.79	.36	.041	76.5	8
2	½ at 1 month; ½ at 3 months..	3.40	10.37	.40	.041	81.8	8
3	½ at 1 month; ½ at 5 months..	4.11	12.64	.52	.033	87.2	7
4	¼ at 1 month; ¾ at 3 months..	4.40	12.81	.57	.019	87.0	7
5	¼ at 1, at 3, at 5, and at 7 months	4.68	12.77	.60	.034	87.3	6
6	¼ at 1 and at 3 months; ½ at 7 months	4.39	12.70	.55	.038	86.4	7
Difference required for significance...		.36	.51	.04	.011	5.3	1

In general, it may be said that the procedures which supplied too much (one half or more) of the total nitrogen when the crop was but one month old were the least efficient producers of sugar. Under the conditions of the testing, where no loss of nitrogen was allowed by leaching or through weed growth, there was little difference between Treatments 4, 5, and 6; these three treatments all received a small application of nitrogen at one month to start them off, and were apparently quite equally able to take the rest of their nitrogen either at 3 months, at 3, 5, and 7 months, or at 3 and 7 months, when the canes had established good root systems.

TABLE III

AVERAGES OF 4 POTS

Nitrogen level	No.	Time of applying N	lb cane	Y%C	lb sugar	% N in juice	Juice purity	% total N in leaf at harvest*
Low	1	At 1 month—(all)	3.97	13.06	.52	.011	87.5	.85
"	2	At 1 and 3 mos. (½ + ½)	3.65	13.10	.48	.011	88.1	.99
"	3	At 1 and 5 mos. (½ + ½)	3.48	13.35	.47	.012	88.1	.92
"	4	At 1 and 3 mos. (¼ + ¾)	4.56	13.70	.62	.011	88.0	.80
"	5	At 1, 3, 5, and 7 mos. (¼ + ¼ + ¼ + ¼)..	3.85	13.57	.52	.012	88.7	.88
"	6	At 1, 3, and 7 mos. (¼ + ¼ + ½)	3.54	13.38	.47	.013	87.4	.99
Medium	1	At 1 month—(all)......	4.24	12.17	.52	.012	86.1	1.20
"	2	At 1 and 3 mos. (½ + ½)	4.98	12.32	.62	.015	87.1	1.20
"	3	At 1 and 5 mos. (½ + ½)	4.86	12.80	.62	.023	87.6	1.49
"	4	At 1 and 3 mos. (¼ + ¾)	5.28	13.62	.72	.015	88.8	1.32
"	5	At 1, 3, 5, and 7 mos. (¼ + ¼ + ¼ + ¼)..	5.67	13.65	.77	.021	88.9	1.40
"	6	At 1, 3, and 7 mos. (¼ + ¼ + ½)	4.75	13.00	.62	.036	86.6	1.40

Nitrogen level	No.	Time of applying N	lb cane	Y%C	lb sugar	% N in juice	Juice purity	% total N in leaf at harvest*
High	1	At 1 month—(all).......	0.76	3.10	.03	.102	55.8	2.06
"	2	At 1 and 3 mos. (½ + ½)	1.55	5.67	.09	.098	70.3	2.19
"	3	At 1 and 5 mos. (½ + ½)	4.01	11.77	.47	.064	86.0	1.91
"	4	At 1 and 3 mos. (¼ + ¾)	3.36	11.11	.38	.032	84.1	1.60
"	5	At 1, 3, 5, and 7 mos. (¼ + ¼ + ¼ + ¼)..	4.51	11.09	.50	.071	84.3	1.80
"	6	At 1, 3, and 7 mos. (¼ + ¼ + ½)	4.88	11.73	.57	.064	85.1	1.80
Amount of difference needed for significance			.62	.89	.07	.020	9.2	...

* = Analysis by R.C.M. of single composite leaf-punch sample.

Several significant interactions between the amounts of nitrogen and the time of its application were indicated:

(a) With a low level of nitrogen, its efficiency was best when the total amount was split ¼ and ¾, and applied at 1 and 3 months. In fact, when the low nitrogen level was applied in this manner, it produced as much or more sugar (.62 pound) as four of the "time schedules" used in applying the medium amount, and significantly more than five of the times of application that were used with the high nitrogen level.

(b) With the medium amount of nitrogen, the poorest result was secured when the total application was made at 1 month. The best sugar yield was made when the total amount was split into 4 equal amounts and applied at 2-month intervals; this was not significantly different, however, from that procedure which furnished ¼ of the nitrogen at 1 month and the rest at 3 months.

(c) With the high level of nitrogen that was used, its total application either at 1 month, or one half each at 1 and at 3 months, definitely reduced the amount of sugar obtained, especially since it greatly depressed the cane growth (see photograph). Applied in either 3 or 4 doses, the cane yields were satisfactory but the juice quality was poorer and the recoverable sugar considerably below that secured from the medium level.

The whole picture quite clearly points out that a proper proportioning and timing of the total nitrogen application for sugar cane is necessary if greatest efficiency is to be secured.

Of incidental interest are the facts that the percentages of nitrogen in the crusher juice, and the per cent total nitrogen in the green leaves at harvest, quite nicely reflect the amounts of nitrogen which were supplied for this cane. R.C.M. analyses made on soil samples taken after harvest, show that but very little available nitrogen remained in the soil from any of the amounts which were supplied.

This photograph, taken before harvest, shows the character of growth resulting from the 3 levels of nitrogen for 3 of the "time" series which were included:

Time No.	Pot No.	Fertilization
1	768 (L)	3 gms. N at 1 month
	793 (M)	6 gms. N at 1 month
	817 (H)	9 gms. N at 1 month
2	773 (L)	1½ gms. N at 1 month and 1½ gms. N at [illegible] months
	796 (M)	3 gms. N at 1 month and 3 gms. N at [illegible] months
	821 (H)	4½ gms. N at 1 month and 4½ gms. N at [illegible] months
3	776 (L)	1½ gms. N at 1 month and 1½ gms. N at [illegible] months
	800 (M)	3 gms. N at 1 month and 3 gms. N at [illegible] months
	824 (H)	4½ gms. N at 1 month and 4½ gms. N at [illegible] months

A Chytrid in Relation to Chlorotic Streak Disease of Sugar Cane

By C. W. Carpenter

The occurrence of an intracellular parasite in sugar cane affected with chlorotic streak disease is discussed in this preliminary report. The parasite is a primordial fungus affiliated with the Chytridiales and for convenience will be referred to herein as a Chytrid. The Chytrids are a group of primitive fungi of the aquatic type, many of which are parasitic upon algae while a few species are among the most notorious parasites of economic plants. This group is considered the most perplexing and the least understood of the Phycomycetes. Such fungi cannot be adequately described and appropriately classified without extensive studies.

The Chytrid discussed in this paper apparently has not heretofore been observed by sugar cane pathologists, nor has a brief search of the available literature revealed any species closely resembling the various phases of its life cycle which have been observed in many varieties of cane. It has been found in chlorotic streak diseased cane from the localities where the disease is more common, viz: Olaa, island of Hawaii; Lihue, island of Kauai; Kailua and elsewhere on the island of Oahu. Affected cane from the Hana District, Maui, has not been studied. In stalks of affected cane this Chytrid has been observed in the young joints close to the growing point, mid-portion, and below the ground level, in the primordial and scale leaves of buds on the green-leaf bearing portions of the stalk, and in the leaves.

In many diseases a suspected parasitic relationship of an organism is susceptible to proof by suitable inoculation technique and reisolation of the organism; in those diseases where intracellular parasites are concerned artificial cultivation of the organism may not be possible for it may be an obligate parasite living only in vital cells. Even direct inoculation of diseased tissue into healthy plants may fail for lack of understanding of the technique required. In this latter group of diseases it is necessary to rely on accumulated evidence from observations of the constant association of the one organism with the disease, and the demonstration of a logical cause and effect relationship of the suspected organism to the observed symptoms, in lieu of indisputable proof of parasitism. The lack of success in our isolation and inoculation work indicates that chlorotic streak disease may belong in the latter category. The accompanying figures illustrate the features of the Chytrid observed after a knowledge had been acquired of finite structures to search for, and the tissues of the plant where they are most readily to be found.

Historical

The disease of sugar cane which now has become generally known as chlorotic streak was reported in Hawaii by Martin (8) in 1930. Attention was first directed to the peculiar yellow leaf streaks occurring on P.O.J. 36 cane in the fields of Olaa Sugar Company, Ltd., by R. K. Conant, Agriculturist. Martin who had recently

visited Java recognized the symptoms as similar to those manifested there by the so-called Fourth Disease. The origin of the name Fourth Disease is stated by Wilbrink (11) to be as follows: Three different sets of lesions had confused the identification of leaf scald disease but upon closer examination had been found to be distinct diseases. These diseases were designated false leaf scald, wilting of the rajoengan (lalas or shoots formed after topping the main stalk), and Fourth Disease.

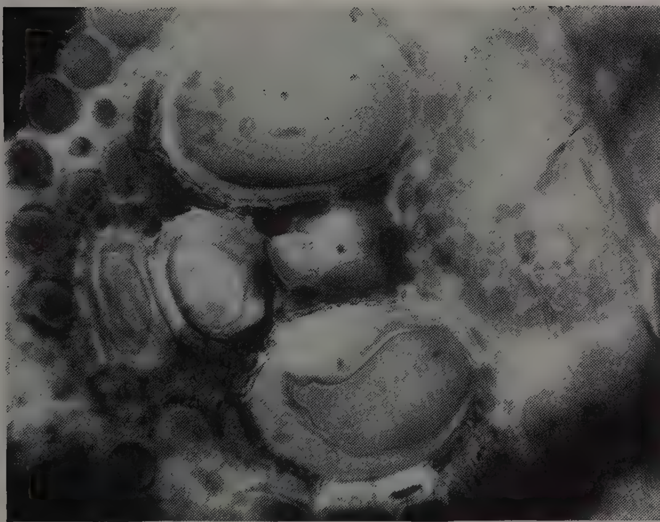
A more suitable name was obviously desirable and the descriptive term chlorotic streak was agreed upon for local use. This name for the disease was informally adopted by sugar cane pathologists at the Fourth Congress of the International Society of Sugarcane Technologists held in Puerto Rico in 1932. The disease was identified in Puerto Rico by Martin, Bell, and Wilbrink at the time of the above Congress, and Bell (4) stated that he had recognized the disease in Queensland in 1929 (2, 3). It was reported in Mauritius by Shepherd (9) in 1934 and in Louisiana by Abbott (1) in 1938.

Symptomatology

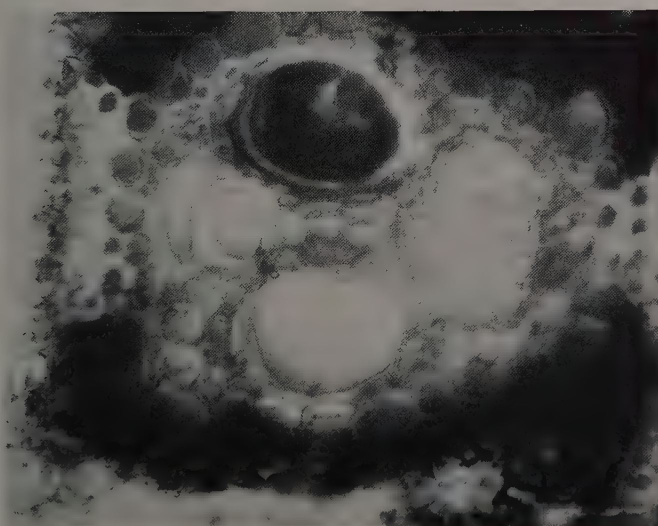
Chlorotic streak disease is characterized by the presence of one or more yellowish streaks on the leaves, as may be inferred from the name. Martin (l.c.) and Wilbrink (l.c.) have furnished complete descriptions with adequate illustrations of the symptoms. The chlorotic streaks follow the veins for varying distances, and may be discontinuous, but rarely extend onto the leaf sheath. They may be from two to five millimeters in width and are typically diffuse or wavy in outline in marked contrast to the sharply defined white or yellow lines typical of leaf variegation, pin-stripe, and leaf scald disease. Here and there the partially decolorized area widens perceptibly, blending with the normal green color of the leaf. Portions of the affected tissue may become necrotic, sear, and of the usual color of dried cane leaves. Where several streaks occur on the same leaf, the greater portion of the surface thereof may be occupied by the long, sometimes wedge-shaped necrotic areas running at a slight angle from the point of origin at the midrib to the edges or tip of the leaf. Except for the variable occurrence of a red discoloration of the vascular bundles in the nodes which may be noticed when the stalks are split, the only other symptom is a more or less evident growth depression. The red discoloration of the fibres in the nodes may be more conspicuous near the base of the plant, but at times may be quite evident in the upper portions, although not all nodes show it in the same intensity. The more susceptible varieties of cane often show a conspicuous discoloration of the vascular elements comparable to that in leaf scald disease, accompanied by more or less hyaline, yellow and red gum deposits in the xylem (Fig. 1).*

The more serious manifestations of the disease are sharply restricted to the wet districts, viz.: the Olaa, Puna and Hilo Districts of the island of Hawaii; the Hana District of Maui; and the windward portions of Oahu and Kauai. When the disease was first recognized in the Territory in 1929 surveys were made to determine

* The photomicrographs were made by the author. The sections were cut by hand from fresh material. None of the preparations had been stained. Only Fig. 3 B made from a preparation shown in Fig. 6, after it had been incubated several days in sterilized water changed daily, may have a doubtful significance to the figures which follow it.



A



B

Fig. 1. A—Gum-like accumulation on the wall of a large xylem vessel of a leaf partially closing the lumen (X 560). (From 1933 report.) B—Occlusions of xylem vessels of the leaf. Note striations or cracks in the thin gum in the lower xylem duct (X 400). (From 1933 report.)

its range and the varieties of cane affected. At that time none was reported on Kauai where it first attained significance in 1939 when the acreage of certain more susceptible varieties was extended. When diseased cuttings are planted in the drier districts, mild symptoms may appear and be visible for a time but in general such symptoms are vague and evanescent. Transmission to healthy cane plants apparently does not occur in such environments. This peculiar dependence upon a wet environment for transmission and symptom manifestation and the characteristic latency with recurrence of symptoms have proved most perplexing.

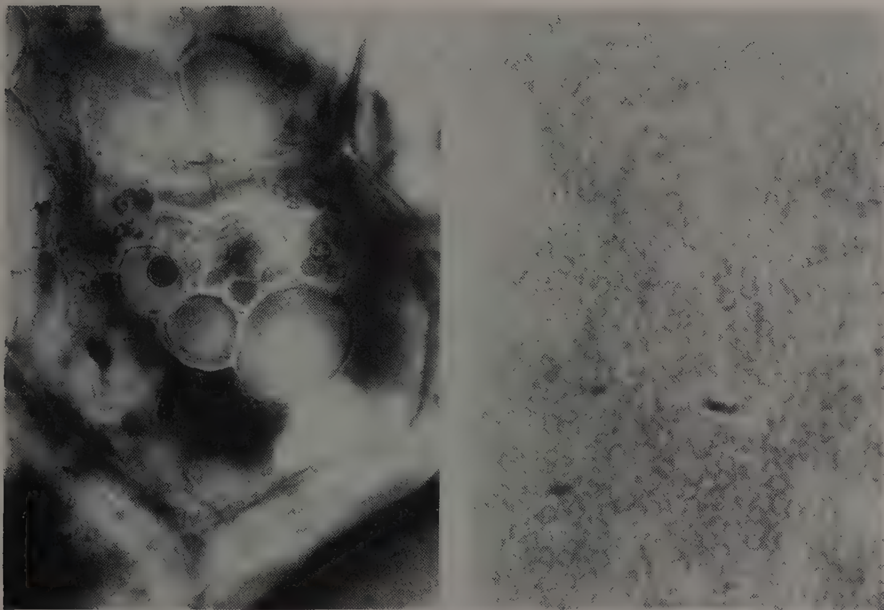
Etiological Studies

Martin and Conant found by experiments that chlorotic streak was transmitted by cane cuttings, and the former demonstrated that such transmission was almost entirely prevented by treating the cuttings in water at 52° C. for 20 minutes. This method was adopted in 1931 for the treatment of all cuttings prior to shipment from the Kailua substation where the disease is prevalent.

The nature of the factors responsible for chlorotic streak and the mode of transmission other than by diseased cuttings have remained unexplained. That another method of transmission exists is quite evident. Annually a considerable number of the new hybrid seedlings contract the disease after being planted in wet localities. Furthermore, cane grown from cuttings selected from apparently healthy plants in localities where symptoms of the disease are not evident, and treated with hot water as an additional precaution, often acquire the disease when grown in wet situations.

Inoculations of healthy plants with tissues and extracts from diseased plants have proved uniformly negative. Wilbrink (l.c.) in Java, and Bell (5) in Queensland report similar results. Extensive bacteriological studies were made by the writer with particular attention to those bacteria having a thermal death point at or below 52° C. with a 20-minute exposure. The only bacterium which produced pathological symptoms following inoculations also proved to be a spore-former with high thermal resistance. Of the many studies of chlorotic streak disease conducted in Hawaii, the observations mentioned in only two reports may have a relation to the Chytrid under discussion. In a report of the features of chlorotic streak disease observed microscopically, the writer (6) mentioned and illustrated spherical spore-like bodies observed in the affected tissues (Fig. 2 *A*). In a project report of May 12, 1937, D. M. Weller discussed and illustrated what he interpreted to be possible stages in the life cycle of a slime mold. He advanced an hypothesis that the disease might be caused by a fungus of the Plasmodiophora type.

Critical mycological investigations have not until recently been undertaken in the absence of a sufficiently convincing demonstration of the occurrence of a fungus in affected plants which might reasonably be suspected. Since all attempts to transmit the infection by direct or other means of inoculation failed, a bacterial or fungus origin, *prima facie,* was not indicated. The virus theory appeared more logical since the symptoms of virus infections in plants are very variable, ranging from a mere stunting to forms of hypertrophy, leaf mottling, striping, chlorosis, etc. The disease under investigation, intangible except in its evanescent leaf symptoms, seemed to belong to the virus type; some such diseases are non-transmissible while others are transmissible only by a refined technique, by grafting, or by a certain insect often in a very exacting and specific manner.



A B

Fig. 2. A—Spherical bodies in vascular sheath cells (X 560). (From 1933 report.) B—Massed spores in culture of a fungus isolated from a drying leaf sheath of 31–2806, and grown as a two-membered culture with a bacterium (X 200). (See following figure.)

Attempts to transmit chlorotic streak from diseased to healthy cane plants by means of contact plantings as well as by the use of various techniques, in the presence of the following insects, proved negative: corn aphis, *Aphis maidis* Fitch; sugar cane aphis, *Aphis sacchari* Zehnt.; rice root aphis, *Yamataphis oryzae* Matsumura; sugar cane leafhopper, *Perkinsiella saccharicida* Kirk.; sugar cane thrips, *Thrips saccharoni* Moulton; onion thrips, *Thrips tabaci* Lind.; and the pink mealybug, *Trionymus sacchari* (Ckll.).

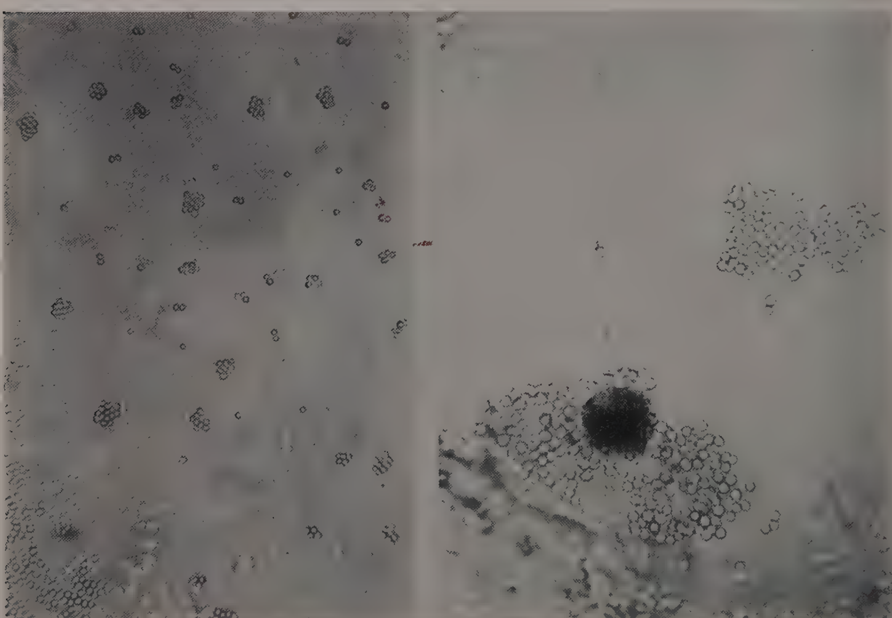
Current Observations

The symptoms of chlorotic streak develop or become more conspicuous when the growth of affected plants is checked by environmental factors. In mild infections the fifth leaf below the rolled spindle leaf may often be the youngest leaf bearing the streaks. In the field, when the growth is checked by drought, or in culture solutions when the growth is checked by a deficiency of any one of the essential chemical elements, particularly potassium, or one of the other bases, calcium or magnesium, the symptoms may be greatly aggravated. Then the streaks, if absent before, may first appear, or the more recently opened leaves progressively develop them, while the streaked older leaves become necrotic and fall prematurely.

In localities where the disease is prevalent, it has become obvious that latent infection is widespread. A great deal more damage than is suspected may be caused by this disease existing in a less active or symptomless form. Competent observers believe that the failure of the variety POJ 36 to maintain the yields in plant and

ratoon crops realized in some localities when this variety was first grown is largely due to chlorotic streak disease. Losses estimated by Martin and Conant from experimental evidence with susceptible varieties range from 15 to 20 per cent. The stalks of diseased cane are appreciably smaller in diameter, ratooning is less vigorous, and the germination of diseased cuttings is noticeably poorer than that of healthy cuttings. In drier localities, that is, in the areas where irrigation is practiced, cane growth is generally maintained at a uniformly rapid rate, the conditions being almost continuously favorable. In such situations chlorotic streak disease has rarely been reported. It is thought that it is not an important factor there, even in symptomless form. The prevailing conditions apparently do not permit infection or favor the progress of the disease when infected cuttings are inadvertently planted.

The frequent development of the disease in healthy control plants, grown from selected cuttings treated with hot water to eliminate possible latent infection, in experiments conducted in the screened greenhouse, served in a measure to reduce the number of factors which might be suspected in the field. When diseased and healthy plants were propagated in the same container in potassium-deficient nutrient solution, infection of the control plants frequently was apparent in four to six months.



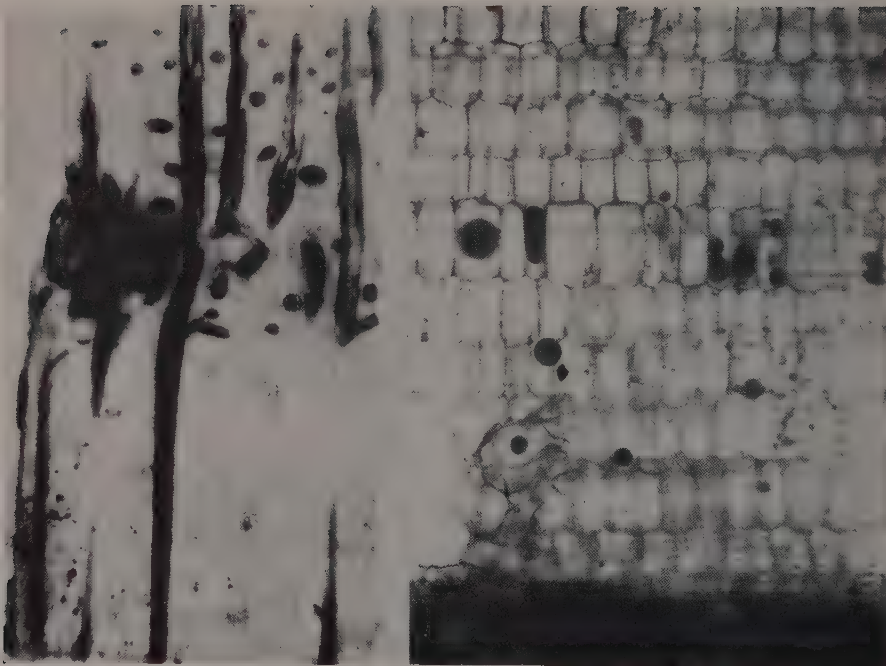
A B

Fig. 3. A—Amoebae forming spores in culture obtained from drying leaf sheath (X 80). (See Fig. 2 B.) B—Spherical spores, similar to those in Fig. 2 B, formed in a preparation in water of a section of chlorotic streak diseased stalk which contained black spherical bodies. (See Fig. 6.) These spores have apparently developed from one of the black spheres (X 160).

A survey of organisms associated internally and externally with chlorotic streak diseased plants growing in the field as well as in nutrient solutions was begun with the view of critically studying parasitic types should any be observed. In this biological survey it was assumed that of the multitude of bacteria, fungi, and protozoa, occurring in and about sugar cane, the great majority of species represented could be regarded as saprophytes or scavengers. It was observed that streaks or broad bands of the leaf sheath often dried prematurely when the attached leaf was severely affected with chlorotic streaks. In examining preparations made from portions of such a dry leaf sheath the occurrence of peculiar spherical spores, similar in appearance to those already observed in the tissues of affected plants and illustrated (Fig. 2 *A*) in the above-mentioned unpublished studies, attracted interest. Cultures made from this material yielded a primitive fungus with amoeboid stages resembling *Chondrioderma* sp. illustrated by De Bary (7, Fig. 183), and associated bacteria. This fungus (Figs. 2 *B* and 3 *A*) and certain of the bacteria were grown as a two-membered culture since the fungus apparently could not be grown as a pure culture even in the presence of dead bacteria. These studies are mentioned here because they led to a thorough reexamination of the similar spherical bodies existing in cane affected with chlorotic streak disease, and which for a long time had been among the few finite foreign structures under surveillance. A suspected relationship of this fungus to the intracellular Chytrid discussed below has not been demonstrated.

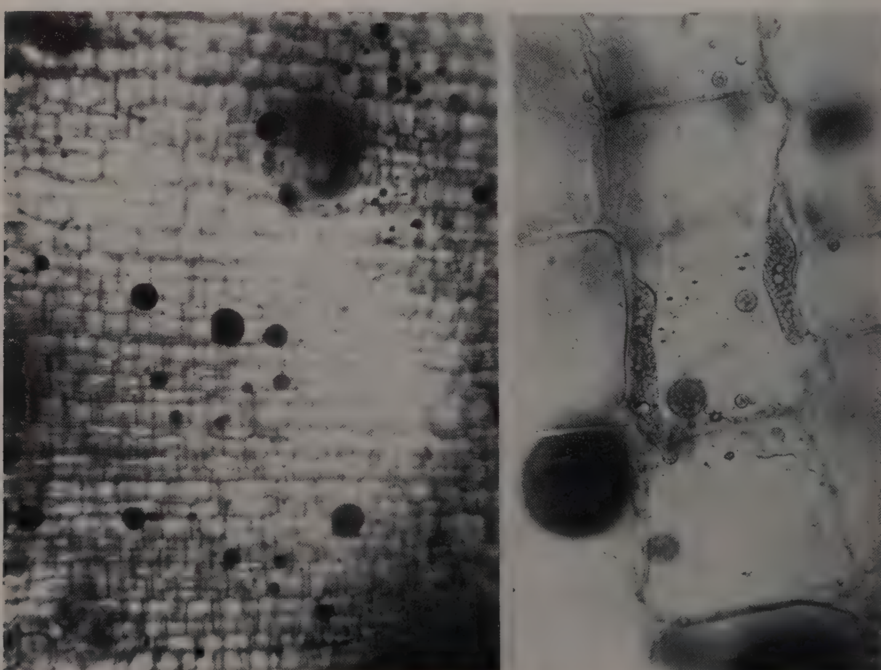
The Intracellular Chytrid:

The parasite, herein tentatively referred to as a Chytrid, is entirely lacking mycelium of the form usual among the fungi, a characteristic of the Chytridiales, in which mycelium is either absent or very rudimentary. The disposition of the Chytrid within the cells of the host suggests that of *Physoderma zeae maydis* in corn as delineated by Tisdale (10). In its most conspicuous form the Chytrid is observed as dense black spheres, opaque under any magnification and with intense illumination, ranging in size from about 5 to 60 microns in diameter, scattered in the parenchyma of the stalk, and assuming the contour of the cells where the latter are not sufficiently large to accommodate the sphere (Figs. 4, 5, 6, and 7). In general, the smaller spheres are almost hyaline, the slightly larger spheres gray, and the larger ones either brown or black, and opaque. In stalk sections about 60 microns in thickness, the assortment of spheres may be seen by transmitted light with a hand lens magnifying 10 to 15 times (Fig. 4 *A*). The fact that these relatively conspicuous occupants of the vital parenchyma cells of the stalks apparently have escaped observation may be due to their localized occurrence and longitudinal distribution. A considerable amount of stalk tissue must be sectioned before this conspicuous phase may be encountered. Such sections examined with the compound microscope reveal the other features of the Chytrid illustrated in the figures. Other spherical bodies present are typically hyaline, and range in size from 3 to 25 microns in diameter, the larger with thick walls. The latter (Fig. 7) resemble hypnospores and appear to be formed by copulation of two units, the content of one sphere entering the other to form the hypnospore, while the empty sphere may remain as a companion cell. These internal spheres resemble the spherical spores of



A B

Fig. 4. A—Longitudinal section through a node in the young portion of a stalk of 31–2806. A group of the black spherical bodies of the Chytrid is shown at the lower left corner (X 7). B—Spherical bodies of the Chytrid in the parenchyma cells in a section of POJ 36 from Olaa (X 80).



A B

Fig. 5. A—Section of seedling cane from Kailua showing the distribution of the Chytrid in the Keimring, near a root primordium (X 60). B—Spherical bodies and thalli with black inclusions in cells of H 109 (X 344).

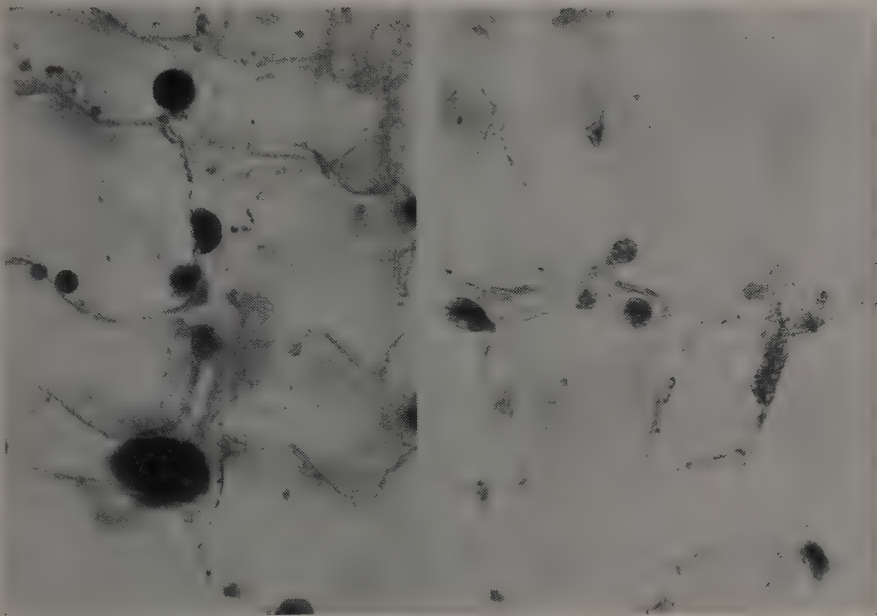


Fig. 6. Thalli of the Chytrid associated with spherical bodies, protoplasmic enlargements (turbinate bodies?) along the cell walls, and connecting strands. In section from stalks of a seedling cane from Kailua (X 400).

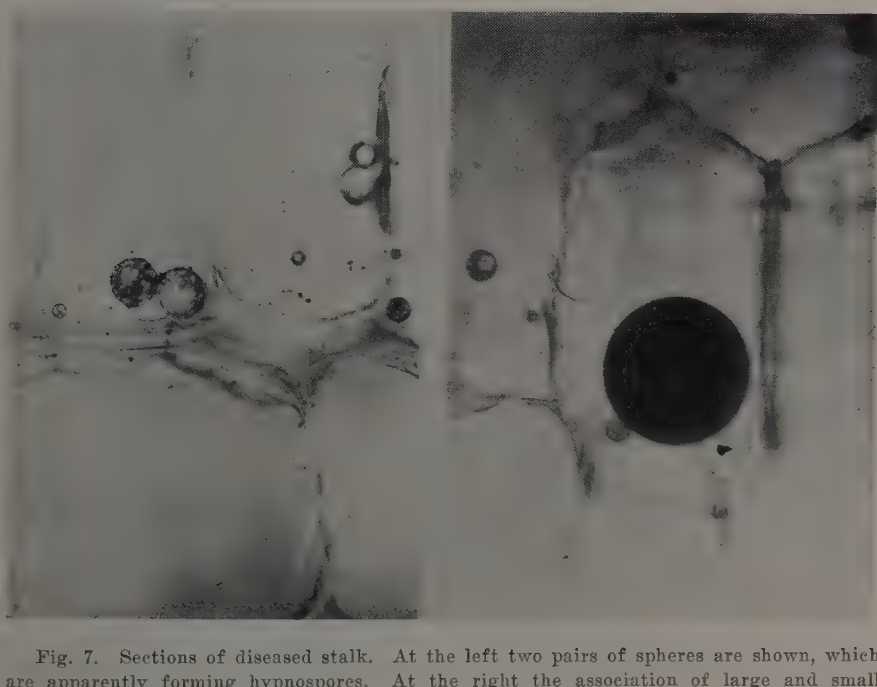


Fig. 7. Sections of diseased stalk. At the left two pairs of spheres are shown, which are apparently forming hypnospores. At the right the association of large and small spheres is illustrated (X 400).

the fungus cultured from the dry leaf sheath above discussed (Figs. 2 *B* and 3 *A*).

Many of the intracellular, small, hyaline or gray spheres of the Chytrid, which are readily identified when in association with a graded series of the units (Fig. 5 *B*), are not easily recognized when occurring alone, being easily confused with starch formations and the normal structures of the host cells, chromatophores and microsomes.

In the parenchyma cells of the stalk associated with the dark spheres, which we may refer to as sporangia, are rounded protoplasmic bodies (Fig. 6) about 5 microns in diameter disposed on the inner surface of the host cell wall. These swollen portions of protoplasm are distributed along a scarcely descernible strand of the fungus leading to the spherical sporangium-like body, suggesting the turbinate bodies and the habit of *Physoderma* sp. The distribution of these smaller swollen masses of protoplasm often suggests the existence of the strand where none can be detected. In Figs. 5 *B*, 6, 8 *B*, and 10 *B* the plasmodium-type of thallus is shown; no streaming of the contents of these thalli, or other motion has been observed, nor has any evidence of cell stimulation or hypertrophy of the host tissue, a characteristic of the Plasmodiophorales, been found. Often in the thallus as well as in some of the spherical sporangia-like bodies, black inclusions in the protoplasm may be clearly seen suggesting that foreign material may be engulfed

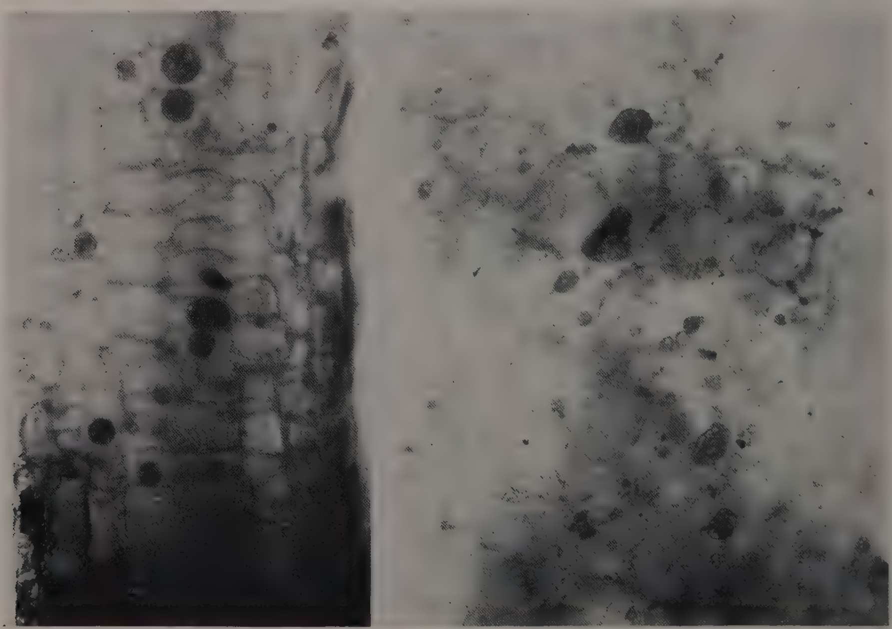
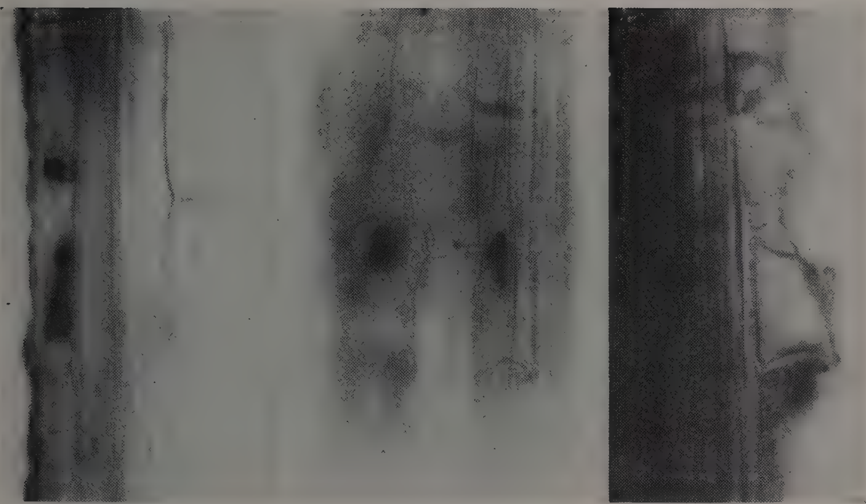


Fig. 8. A—Section of a primordial or scale leaf deep within an eye on the green-leaf bearing portion of a stalk of POJ 36 cane from Olaa. The sporangia-like bodies of the Chytrid are occupying many of the cells (X 160). B—Naked protoplasmic thalli of the Chytrid in the distal portion of a primordial leaf lying next within the leaf shown in A (X 400).



A B C

Fig. 9. Occurrence of thalli of the Chytrid in the cane leaf as observed in a longitudinal section through the proximal end of a chlorotic streak in 31–2806. A—Thalli resting upon and others within the upper epidermis (X 160). B—In parenchyma cell near epidermis, and within the lumen of an anastomizing vein (X 344). C—A thallus upon, and another partly beneath the projecting point of a trichome on the lower epidermis (X 344).

(Figs. 5 *B,* 6, and 10 *B*). Such inclusions often serve to identify the fungus when otherwise its presence in the cells of the host might not be observed.

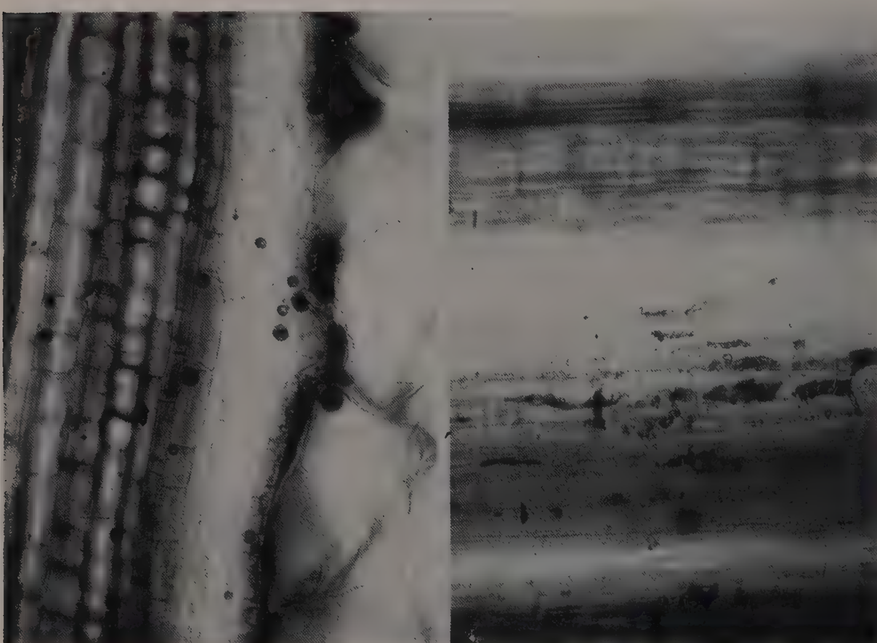
The developmental stages of the intracellular Chytrid have not been sufficiently observed to interpret the phases of the life cycle which are shown in the figures in order to record the nature of the organism. The large black sporangia-like units apparently prepare for germination by developing a gelatinous cap (Fig. 11 *A*), while later numerous large and small oil drops and vacuoles are formed, the whole becoming somewhat translucent, or the contents may issue as minute spherical sporangia (?), or again as a thallus-like outgrowth (Fig. 11 *B*). In the stalk cells are also observed irregular-shaped units of this plasmodium-like material as well as small spheres, and similar structures are found among the chloroplasts of the leaves and in the rudimentary leaves in the cane bud (Fig. 8). The zoospore and amoeboid stages of the fungus, if such stages are developed, have not been identified.

The various stages of the Chytrid have been most frequently observed in the parenchyma both above and below the nodes, near the center of the apparently sound stalks as well as close to the rind. They are to be found close to the xylem and phloem, and occasionally therein, but the parenchyma and storage tissue are apparently preferred. In the nodes the sporangia-like bodies have been observed in great abundance in the plexus of vascular strands. As shown in Fig. 10 the fungus occurs just under the epidermal cells of the rind, and portions of the plasmodium-like thallus have been seen in juxtaposition within and without the rind immediately above the bud, indicating clearly a point of entrance or exit of the

parasite. A similar observation was made with respect to the leaves where it also occurs in the parenchyma cells and the chlorophyll-bearing cells (Fig. 9).

Discussion

The course of chlorotic streak disease is understandable if we may presume it to be similar to that of *Physoderma zeae maydis* in the corn plant, such a presumption being purely for the purpose of illustration without any suggestion that the species or the genera of the two organisms are considered identical. In the corn disease, infection takes place in the parts of leaves, leaf sheaths and culms so protected from sun and wind that rain water remains for protracted periods, according to Tisdale (l.c.). The latter mentions the following factors which influence the development of the *Physoderma* disease of corn: The more important factors are moisture and temperature. In dry seasons the disease is restricted to low wet land where the atmosphere is moist. Under these conditions the plants are more likely to retain the sheath and bud water until the spores can germinate and produce infection. In certain instances the most vigorous plants sustain the most severe attacks, apparently because they shield the free water held beneath the sheaths. The minimum temperature at which the spores germinate is rather high, 23° C. The disease is limited to the Southern and Southeastern States, and is rare farther

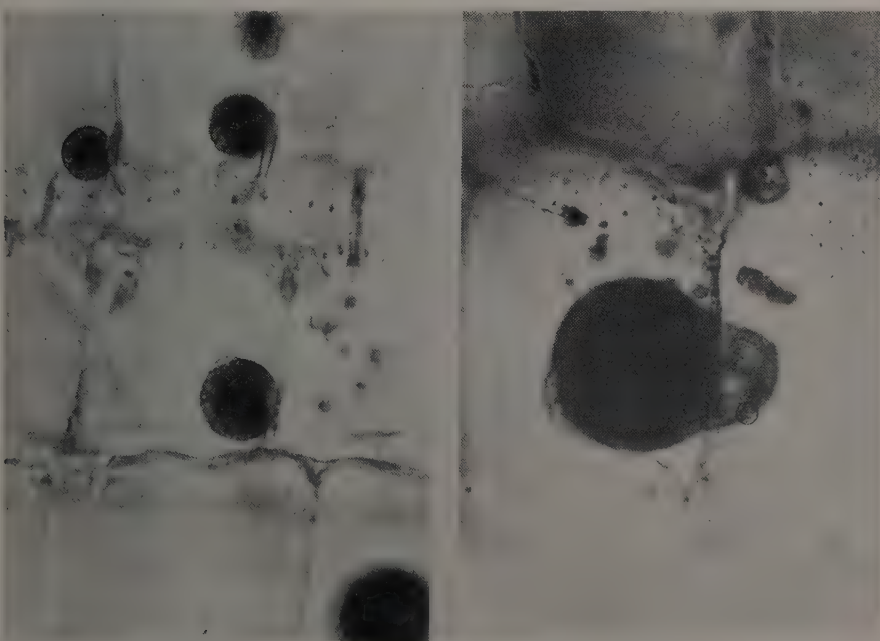


A B

Fig. 10. A—Section of a young node of H 109 showing the coincident occurrence of the thalli and spherical bodies of the Chytrid beneath epidermal cells which have formed blister galls after infestation with *Tarsonemus spinipes* (X 160). B—Another portion of the same section showing the thalli with black inclusions deep within the stalk (X 160).

west apparently on account of the semi-arid conditions there. The fungus enters the culm and often so weakens it that the plant falls.

In chlorotic streak disease we have an analogous history. The disease seems similarly restricted by climatic conditions. A similarity of the leaf streaks to the early lesions of *Physoderma* disease of corn (Tisdale l.c. Plate 12, at top) was noticed early in the investigation but the lack of the characteristic spores ruled against any similarity of origin. In the cane disease, propagation by cuttings being customary, an infected stalk serves as a reservoir of infection. Apparently localized portions of the stalk may be permeated with the fungus and the plant be stunted, yet leaf symptoms may appear only when water stands in the sheaths. Cane of the variety H 109 selected at Makiki as healthy showed the presence of the fungus as an intracellular parasite in vital tissues not far below the growing point, indicating that latent infection in wet localities or in the rainy season may be common and unsuspected. It might be inferred that if this fungus is present in cane showing no leaf streak symptoms, then the fungus is not concerned as a causal agent. It may be argued that an occupation of vital cells of the cane plant cannot be considered a normal condition when the occupant is so apparently of parasitic nature; it may also be stated that the fungus, although found in apparently healthy cane at Makiki where the disease occurs, was not found in cane from Waipio, indicating that it may not be present in cane in localities where the disease is rare, except in affected



A B

Fig. 11. A—Section of H 109 stalk showing a spherical body of the Chytrid which is developing a gelatinous cap apparently in preparation for germination (X 400). B—Apparent germination of a spherical body after 16 hours in boiled tap water. The thallus seems to have penetrated a host cell wall and to be cutting off small spheres (X 400).

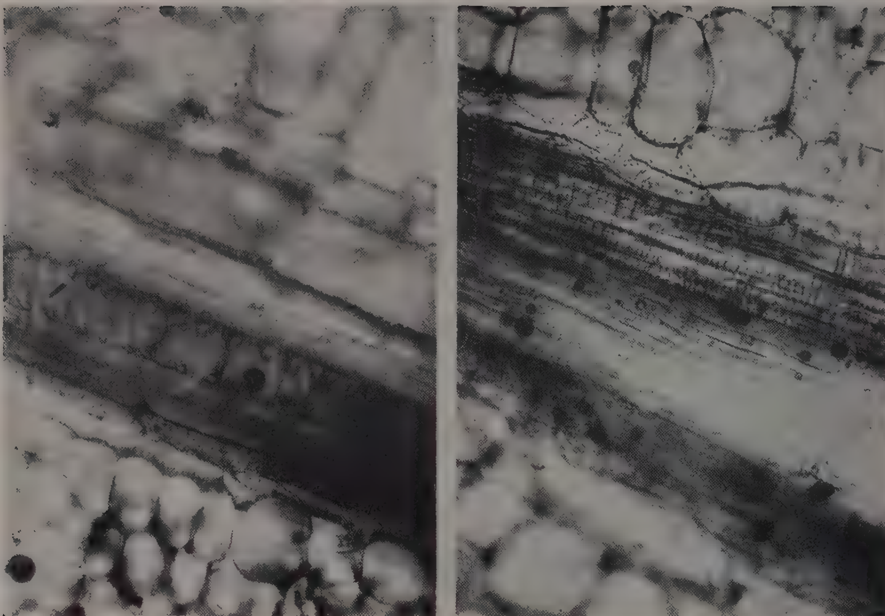


Fig. 12. Sections of a stalk of POJ 36 from Olaa showing occurrence of the Chytrid in vascular tissues (X 160).

cane. It is believed that latent infection is much more prevalent in the wet districts than is generally realized. This presumption may account for some of the improvement in germination and growth of plant cane following the hot-water treatment of cuttings.

Mention has been made of the yellow or red gum deposits in the conducting vessels of the vascular system, particularly in the nodes. This gum which may partially or entirely block certain vessels (Fig. 1) appears to be a plant product rather than an accumulation of foreign organisms. Such deposits are also found in the xylem of the leaf but in general the plugging of the xylem does not appear with sufficient constancy to account for the symptoms of leaf streaking. If the plugging of such ducts in the stalk were responsible for the leaf streaks we would expect that frequently the streak would extend down the sheath. It remains an open question whether the occlusion of the bundles in the leaf causes the typical streaks, or if these are due to a more direct action. In the leaves the Chytrid occurs as plasmodial bodies and small spheres in intimate association with the chlorophyll bodies in the cells which could account for their disintegration and the accompanying chlorosis, while the plasmodial bodies within and on the epidermis, and those on the trichomes, apparently are in advantageous positions to infect contacting leaves (Fig. 9).

The observations discussed herein are intended as a progress report and may serve as an introduction to the etiology of chlorotic streak disease of sugar cane. A complete understanding of this obscure disease and its natural means of trans-

mission other than by diseased cuttings are subjects for further inquiry. Whether the Chytrid described is the agent causing the symptoms may not be as significant as that this intracellular parasite, apparently hitherto unknown, may, in the absence of any gross symptoms, contribute to growth depression, poor germination and thin stands of cane in plant and ratoon crops, and the deterioration of mature cane, in localities where wet conditions prevail.

Literature Cited

(1) Abbott, E. V., 1938. Chlorotic streak of sugarcane. The Sugar Bulletin, Vol. 16, No. 20, pp. 4–5.

(2) Bell, A. F., 1929. 29th Annual Report, Bureau of Sugar Expt. Stns., Queensland, p. 37.

(3) ————, 1932. 32nd Annual Report, Bureau of Sugar Expt. Stns., Queensland, p. 46.

(4) ————, 1933. Proc. Intern. Soc. Sugar Cane Tech. Puerto Rico, pp. 81–82.

(5) ————, 1939. 39th Annual Report, Bureau of Sugar Expt. Stns., Queensland, pp. 54–55.

(6) Carpenter, C. W., 1933. Experiment Station, H.S.P.A., Monthly Report, August, 1933. Project Report, August 16, 1933.

(7) De Bary, A., 1887. Comparative Morphology and Biology of the Fungi, Mycetozoa and Bacteria, Fig. 183, p. 423.

(8) Martin, J. P., 1930. Chlorotic streak disease of sugar cane. The Hawaiian Planters' Record, 34: 375–378. (With colored plate.)

(9) Shepherd, E. F. S., 1934. Ann. Rpt. Mauritius Dept. of Agric. for 1933, p. 22.

(10) Tisdale, W. H., 1919. Physoderma disease of Corn. Journ. Agr. Res. 16: 137–154.

(11) Wilbrink, G., 1933. Diseases resembling leafscald. Proc. Intern. Soc. Sugar Cane Tech. Puerto Rico, Bul. 117, pp. 1–8.

The Role of the Spectrograph in the Analysis of Agricultural Materials

By Stanley S. Ballard

A review of the literature of analytical chemistry of recent years will reveal an increasing number of references to the use of the spectroscope. This instrument was invented over two centuries ago and was used as early as 1860 by Bunsen and Kirchhoff in identifying elements. However, it has been used in a routine fashion in chemical analysis only during the present century. In such work, called "spectrochemical analysis," the photographic form, the *spectrograph,* has largely supplanted the original spectroscope, which was a visual instrument. One of the fields in which the spectrograph was first used successfully was metallurgical analysis. This was due probably to the circumscribed nature of the analytical problems—the determination of a half-dozen minor elements in the presence of the major element, iron. However, in the last decade its use has spread to many other fields, including agriculture, and since 1931 excellent spectrographic equipment has been available in this Experiment Station. The present paper is based on the three years' experience of the writer as Consultant in the Spectroscopic laboratory of this Station.

It should be noted that extravagant (or perhaps more correctly, over-enthusiastic) claims have been made for the spectrograph as an analytical tool by some spectroscopists and by manufacturers of spectroscopic equipment. It must be stated that the spectrograph is *not* the panacea for all analytical ills. In the opinion of the writer the spectrograph is a very powerful analytical tool, but is most effective when used not individually, but rather in conjunction with the standard bench methods. Some types of analysis can be carried out more easily and accurately by chemical methods; others by the spectrograph. Therefore, it is desirable that the analyst should appreciate the particular advantages of each of these two technics. It is the purpose of this paper to evaluate the usefulness of the spectrograph in the chemical analysis of agricultural materials, and to give illustrations of such use.

Both quantitative and qualitative analyses can be performed with the spectrograph. The quantitative methods are to be preferred over chemical methods only in cases where the chemical methods are difficult or uncertain; for example, where very small samples are available, where trace amounts are to be determined, or where one metal is to be determined in the presence of another metal which is its chemical homologue, such as rubidium in the presence of potassium. The average error to be expected in the best quantitative spectrographic analysis is around 2 per cent, which cannot compare with that usually obtained by chemical methods. However, the accuracy of spectroscopic analysis is constant in per cent, while that of chemical methods is constant in absolute amount. Therefore, while spectroscopic methods cannot ordinarily compete in the range of large concentrations, say over one per cent, they will usually have an advantage over bench

methods in the lower ranges, say less than 0.1 per cent, and running down in some cases to thousandths of a per cent, where the above-mentioned precision is still attained. The speed of spectrographic determinations has often been emphasized, but here again one must evaluate the situation in terms of the particular element sought and the competing chemical technics. The chemist's new colorimetric methods doubtless offer entirely as much in the way of speed. It is probable that there could be developed "rapid spectrographic methods" of the approximate accuracy of the well-known rapid chemical methods used so successfully in Hawaii, but as yet there has been no call for them.

The *qualitative* analysis of agricultural materials by the spectrograph offers several attractive advantages, which are enumerated below. First it should be pointed out that in the technic employed in this laboratory, namely the use of arc excitation and a large quartz spectrograph, some sixty of the elements can be detected. This list includes all the metals, the metalloids or semi-metals boron, carbon, silicon, phosphorus and arsenic, and the non-metal fluorine in the presence of calcium. The outstanding advantages of qualitative spectrochemical analysis are:

1. The spectroscope does not make group tests, but tests for individual elements. Therefore an unexpected element is as likely to be detected as is the most highly expected. No previous knowledge of the nature of the sample is necessary.
2. Many elements may be detected at the same time. That is, in the single operation of taking a spectrum plate as many as 25 elements may very well be recorded.
3. A permanent record is secured, which can be examined subsequently for elements not sought at the time of making the original analysis.
4. The method is rapid, at least when several elements are being sought. For example, a plant material can be completely analyzed qualitatively (for the elements determinable spectroscopically) in a single working day, with perhaps two-dozen major, minor and trace constituents being detected.
5. The sample is given a minimum amount of handling and preliminary treatment. It is either tested directly, ashed in platinum, or ground fine in an agate mortar, and ordinarily no reagents are used. Therefore, the chance of accidental contamination is very small.
6. Only small amounts of material are needed. As much as 5 mg. of a soil, fertilizer or plant ash is often sufficient for a complete analysis.
7. Extreme sensitivity is secured in the detection of certain elements. For example, the presence in a sample of as little as one-tenth of a part per million of copper or of sodium can easily be detected.
8. Semi-quantitative estimates, accurate usually to the nearest factor of 10, can be secured with little added work. This makes the method much more valuable than the "present or not present" type of qualitative analysis.
9. Minor differences in the composition of substances of similar major composition are readily detected by the use of a comparison technic.

Fundamental Principles of Spectrochemical Analysis

Chemical analysis by the spectroscope is based upon the fact that each element has a characteristic spectrum which identifies it clearly and definitely. This

spectrum is due to the valence electrons of the element. It may consist of only a few lines or of many thousand spectrum lines, which lines may be distributed throughout the infrared, the visible and the ultraviolet regions of the spectrum. For analytical purposes the region covered by the quartz spectrograph and recorded on panchromatic films and plates, namely, that between the red and the deep ultraviolet, contains the important lines of practically all the metals. In this region boron has only two strong lines, silicon has some twenty, copper has several hundred, and elements such as iron, uranium, and the rare earths have several thousand. The important lines to use in qualitative analysis are those which appear when the smallest amounts of the elements are present. These lines, called the "ultimate lines," are known for all the elements and are catalogued. They first appear when the element is present in quantity just sufficient to detect. As the quantity present increases, the ultimate lines become stronger and other less sensitive lines begin to appear. Semi-quantitative estimates of the amount of an element present are indeed based upon this performance on the part of the ultimate lines and the next most sensitive lines. Strict quantitative analysis is based entirely upon the intensities of certain selected spectrum lines, usually in comparison with the intensities of lines of internal standard elements present in known amounts.

Experimental Technic

In order to produce the spectrum of its constituents, a substance must first be subjected to some type of thermal or electrical excitation. The four common types of excitation are the Bunsen flame, the electric arc, the high-voltage spark and the electric discharge of a gas under reduced pressure, as in a Geissler tube. The direct-current arc method is preferred for the spectrochemical analysis of agricultural materials, because the technician can be protected easily from the low voltage (never over 300 volts), and particularly because non-conducting powders such as soils and plant ashes can be tested without special treatment. An arc is struck between two graphite or sometimes two copper electrodes, which electrodes must be of the purest obtainable material. The lower end of the top electrode is pointed, while in the upper end of the lower electrode is drilled a small cavity, into which is placed a few milligrams of the powdered sample (3). An arcing time of 2 to 10 minutes at a current of 4 to 8 amperes is usually sufficient to volatilize the sample completely. The light in the arc stream is given off by the atoms and ions of the sample elements as well as those of the electrode material. This light is focused by the condensing lens on the entrance slit of the spectrograph. The spectrograph breaks the light up into its components—not the rainbow colors of the ordinary continuous spectrum, but sharp lines which may be colored (if they are in the visible spectral region) or colorless and invisible (if they lie in the infrared or ultraviolet regions). These lines, which arrange themselves in the order of wave length, are recorded photographically. In work of this sort an instrument whose optical parts are of quartz rather than glass is ordinarily used, since glass does not transmit the deep ultraviolet, in which region lie many lines of analytical importance.

Fig. 1 shows the spectrograph, which is a large instrument of the Littrow type. The Littrow mounting has the advantage of a long optical path so that the dis-

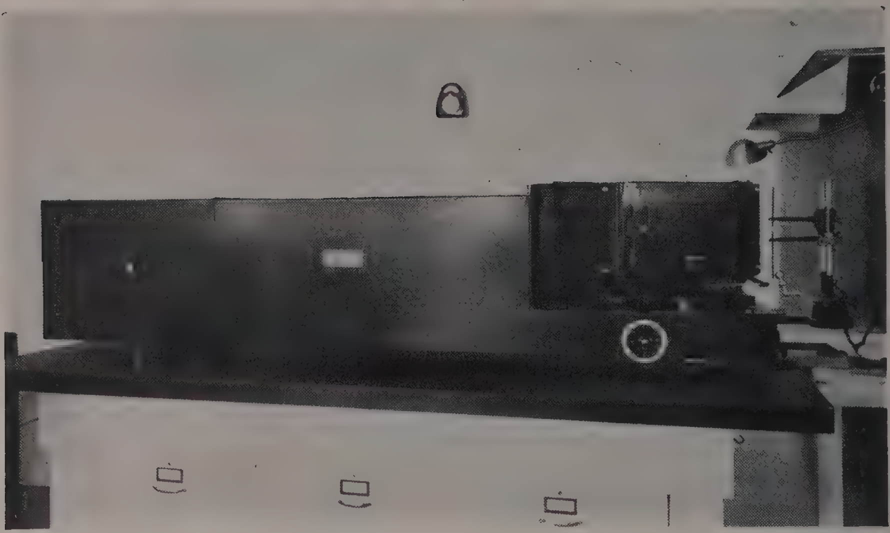


Fig. 1. The large Littrow quartz spectrograph. (Side view.)

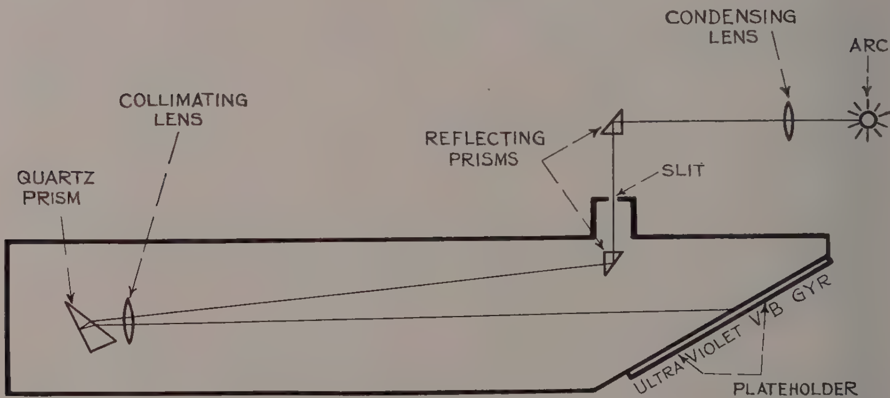


Fig. 2. Diagram (top view) of the large quartz spectrograph, with all important optical parts labeled. The path followed by a ray of violet color is shown.

persion is large, but by doubling back the light path, as shown in Fig. 2, this is achieved without too much sacrifice of laboratory space. Also, there is a saving in the number and size of expensive quartz optical parts necessary. Into the plate holder at the right-hand end of the instrument (see Figs. 1 and 2) can be inserted appropriate photographic plates; non-panchromatic plates for work entirely in the ultraviolet and panchromatic plates for work in the visible region of the spectrum. The plates used are not of the usual commercial type, but are those manufactured especially for scientific work in spectroscopy and astronomy by the Eastman Kodak Company. In a small darkroom adjoining the spectrograph room there are facilities for developing, fixing, washing and drying the spectrograms.

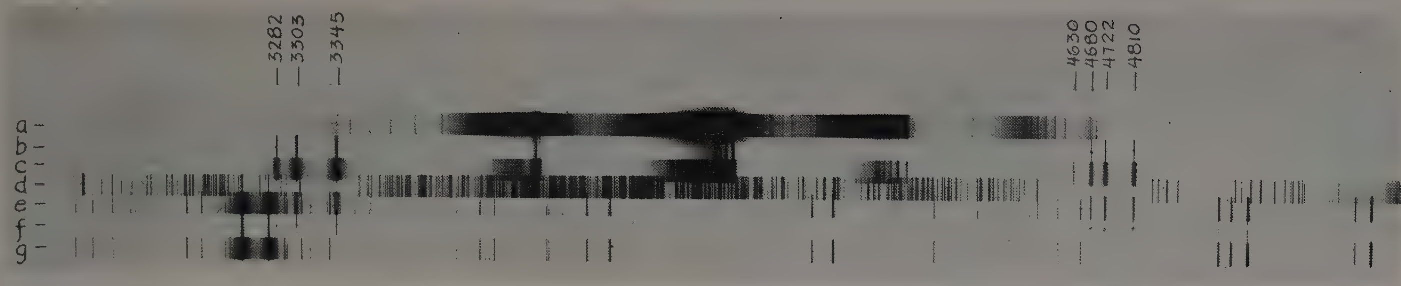


Fig. 3. "Range I" zinc standard plate, showing the sensitive arc lines that lie in this wave-length region. The lines are dotted, and their approximate wave lengths in angstroms are given above. The "line" at 3303 is really a close doublet, while that at 3345 is a close triplet. The heavily blackened areas in the upper three spectra are the cyanogen bands produced by a carbon arc run in air. (See Fig. 6 caption for a further description of the various spectrum strips.)

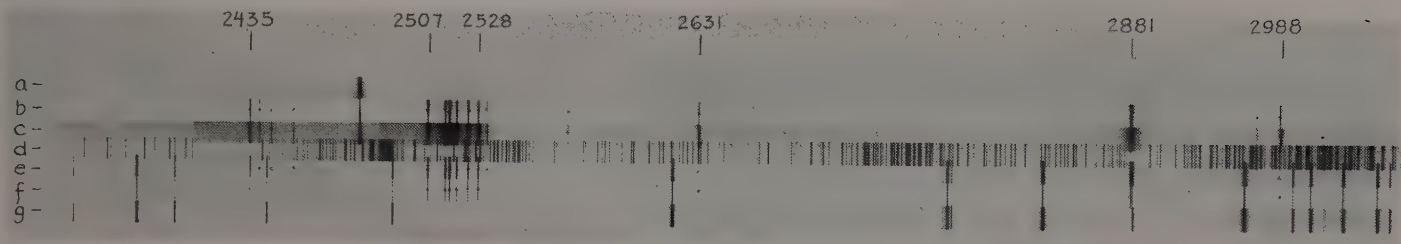


Fig. 4. "Range II" silicon standard plate, showing all but two of the strong arc lines of silicon. All silicon lines are dotted, and the wave lengths of several of the strongest ones are given. (Cf. Fig. 6 caption.)

Analysis of the Spectrograms

With an instrument of such large dispersion, two plates, each 10 inches in length, are required to cover the available wave-length range and include the important analytical lines of the sixty-odd arc-sensitive elements. "Range I" includes the visible part of the spectrum and the near ultraviolet, as shown in Fig. 2, while "Range II" lies entirely in the ultraviolet. Therefore, to obtain a complete qualitative analysis of the metallic constituents of a sample, two spectrum plates must be taken. This is no great task, since the adjustments necessary to shift the instrument from one range to another can be made in a very few minutes.

Efforts have been made to expedite spectrogram analysis and reduce it to a matter of simple routine. The first step was to make "standard plates," on each of which appear the important spectrum lines of a single element. There are now available some eighty of these spectrograms, each of which is marked to indicate the ultimate and other sensitive lines of the element concerned. The standard plate of zinc, whose sensitive lines lie in Range I, is shown in Fig. 3, while that of silicon, a Range II plate, is shown in Fig. 4. The plate to be analyzed can be compared to a succession of standard plates by the ingenious device shown in Fig. 5. This comparator was supplied by Adam Hilger, Ltd., of London, but was altered radically in the Experiment Station shop in order to increase its flexibility and general utility. If only certain specified elements are sought, their standard plates are compared in succession with the unknown plates, and their presence or absence in the sample is determined immediately. If on the other hand a complete metallic

Fig. 5. The outer office and analysis room. On the end of the table at the right is the Judd Lewis comparator, with which plate analysis is effected. Note the pens and colored inks used in marking the plates during analysis. The plateholder end of the spectrograph can be seen through the door at the left.

analysis of the unknown is desired, it may be simpler to use a pair of spectrograms on which appear the most sensitive lines of all the arc-sensitive elements. We have developed a modified type of standard plate called an "elimination plate," on which are photographed and identified all the sensitive lines of those elements which occur in practically every agricultural material, namely, phosphorus, potassium, silicon, sodium, calcium, magnesium, aluminum, manganese, copper and iron. The identification of lines due to other elements is rendered much simpler by the early identification and elimination of the lines of these common elements.

As each spectrum line is identified it is so marked by dotting it with colored ink and writing the symbol of the element in the margin of the plate (see Fig. 6). The number of lines dotted for each element and the blackness or intensity of these lines is used in arriving at a semi-quantitative estimate of the amount of that element present in the sample.

Examples of the Qualitative Spectrochemical Analysis of Agricultural Materials

Plant Materials:

Fig. 6 shows the spectrograms of the ash of plant material from the growing-point region of a stalk of H 109 sugar cane grown at Makiki. The spectrum lines of 12 elements are recorded. These may be grouped into the major elements (present, say, in excess of one per cent), the less plentiful or minor elements (present in from 0.01 per cent to one per cent) and the trace elements (present in less than 0.01 per cent), as shown below:

METALLIC ELEMENTS PRESENT IN ASH OF NON-MILLABLE TOP (GROWING-POINT REGION) OF H 109 SUGAR CANE

Major	Minor	Trace
Potassium	Manganese	Boron
Phosphorus	Strontium	Barium
Silicon	Magnesium	Copper
Calcium	Iron	Sodium

This is a complete spectrographic analysis of this sample, and accounts for all the metals present. Zinc, if present in trace quantity, must be less abundant than 0.01 per cent, aluminum less than 0.001 per cent, etc., where the amounts quoted refer to the ultimate sensitivity of detection of these elements (1).

A more exhaustive survey of the mineral elements present in different parts of the sugar cane plant is being made. In this study the number and amounts of elements found in the green leaves, dead leaves, growing point region, green-leaf millable cane and dry-leaf millable cane of a single stalk of H 109 sugar cane are being compared.

Fertilizers:

An exhaustive spectrographic study of the metallic composition of certain commercial fertilizers has been made, and the results published in this journal (1). This survey shows the major differences among the metallic contents of twelve

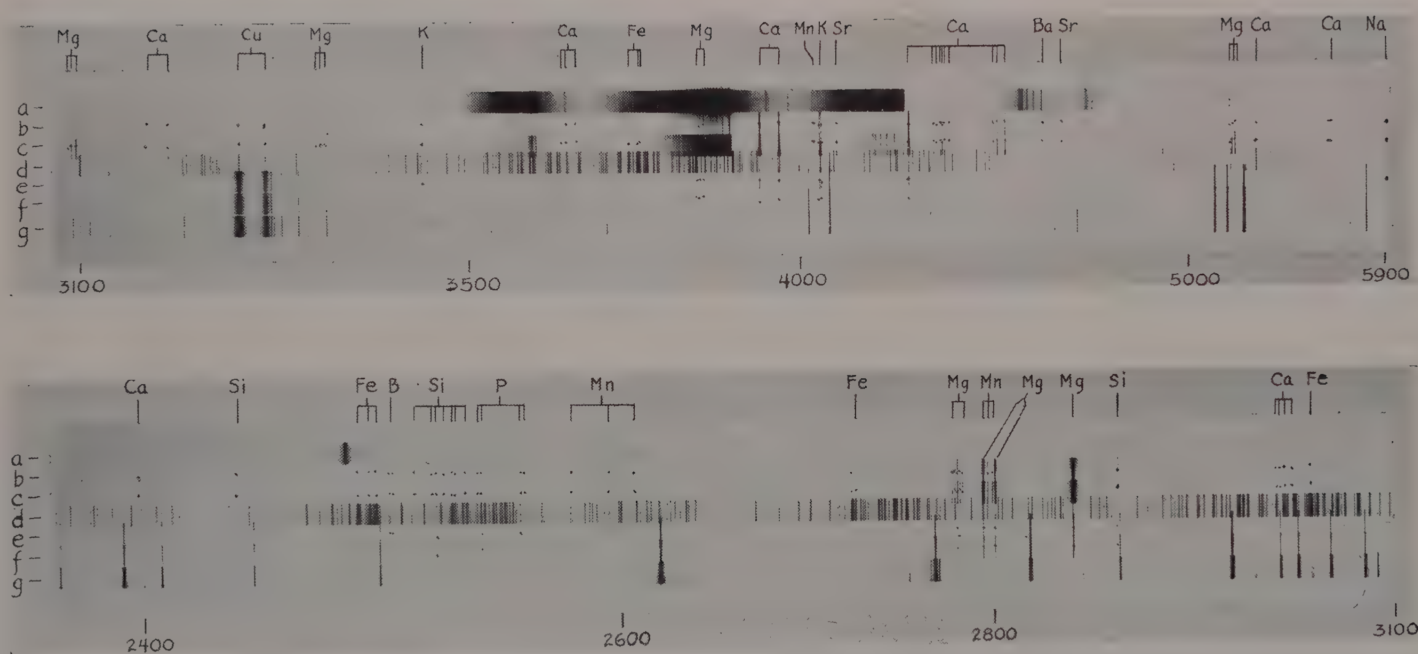


Fig. 6. "Range I" (above) and "Range II" spectrograms of plant ash: growing-point region of H 109 sugar cane. The stronger lines due to the sample are dotted and their identifications are given above. Approximate wave lengths in angstroms are given below. The arrangement of the seven strips on each plate is: (a) bare graphite electrodes, (b) graphite electrodes with sample burning, (c) duplicate of (b), with more sample added or a longer exposure time, (d) iron arc spectrum for wave length identification, (e) copper electrodes with sample burning, (f) duplicate of (e) as above, and (g) bare copper electrodes. The strips are photographed in the order a, b, c, d, g, f, e.

commercial fertilizers used in Hawaiian agriculture. Of particular interest are the data on the occurrence of the so-called "minor plant nutrients," iron, copper, zinc, manganese and boron. In all, 21 elements were encountered. Many of these are not now regarded as essential to plant growth, but may someday be found to be essential, or perhaps toxic when present in larger than trace amounts.

Raw Sugar Composites:

At the request of the Sugar Technology department, ash analyses were made of the 1937 and 1938 raw sugars, composited by Islands. The results for the two years were quite similar, as 19 metallic and semi-metallic elements were found to be ash constituents in each case. The results for the 1938 composites are given below, with percentage estimates of the composition of the low temperature ash of the sugars. These estimates are not to be considered as quantitative figures, as they may easily be in error by a factor of 5 or 10, that is, 500 to 1000 per cent. However, they show clearly which are the major, which are the minor and which are the trace elements. Although small differences were suggested among the compositions of the composites for the four Islands, these differences lie at the precision threshold of the technic used and cannot be reported with confidence, with the exception that a small trace of silver was found in the Maui ash only.

ESTIMATED METALLIC COMPOSITION (IN PER CENT) OF THE ASH OF 1938 RAW SUGAR COMPOSITES

Potassium	5	Lead	0.01
Silicon	1	Chromium	0.01
Phosphorus	1	Magnesium	0.01
Iron	0.5	Sodium	0.01
Calcium	0.1	Boron	0.01
Titanium	0.1	Copper	0.005
Aluminum	0.1	Strontium	0.005
Manganese	0.1	Barium	0.005
Tin	0.05	Nickel	0.001

It will be noted that the more plentiful elements listed here are those found in sugar cane in largest amounts; potassium, silicon, phosphorus and calcium, plus the most common soil metals, iron, aluminum and titanium. Some of the other elements found in the raw sugars may very well have been introduced in the milling process. This list includes additional iron and calcium, and the tin, lead, copper, nickel, etc. An analysis using more quantitative methods and directed, say, to the amount of copper, lead, tin and nickel in the raw sugars from individual plantations should give interesting information on certain features of the milling methods in use on these plantations.

Growth-Failure Soils and Plant Materials:

A perplexing situation in certain cane fields is the occurrence of small but definite areas of very poor growth, called "growth-failure" areas. At the suggestion of the Pathology department, green and dead leaves from sugar cane growing in the good and in the growth-failure areas, as well as the soils from these areas, were analyzed. Significant differences in the amounts of any of the important

mineral elements were sought. The elements for which this was done were phosphorus, potassium, calcium, magnesium, iron, copper, manganese, boron, zinc and silicon. No definite differences which might denote a nutritional deficiency or a toxicity were noted, except for the case of manganese, which appeared to be present in larger amounts in the cane leaves from the poor growth area.

Insects:

Quite a different type of material was studied in the course of the analysis of three arthropods, undertaken at the suggestion of one of the Station entomologists. The three species were selected to cover a wide range of feeding habits. They included the sugar cane beetle borer, the common centipede, and the Cypress cockroach. The number and amounts of the mineral elements present in the ash of the species reflected their feeding habits. Nineteen elements were encountered. Those found present in all three species are listed below:

METALLIC ELEMENTS PRESENT IN THREE ARTHROPODS

Major	Minor	Trace
Phosphorus	Iron	Zinc
Silicon	Manganese	Aluminum
Potassium	Copper	Strontium
Calcium	Sodium	Barium
Magnesium		Titanium*

* No titanium found in centipede ash.

The additional trace elements lead, boron, chromium and nickel were found in the cockroach ash, and a trace of tin was found in the beetle borer ash. These results are discussed briefly elsewhere (2).

Cane Sirups:

At the request of the Ewa Health Center, several samples of a sugar cane juice concentrate were analyzed spectrographically. Of chief interest were the elements copper and cobalt, but information was desired also on other elements of nutritional significance.

The first sample analyzed was reported to contain copper "equal to, or perhaps in excess of, one part per million." This sample was later analyzed by quantitative chemical methods by L. E. Davis and was found to contain 1.7 parts per million of copper. A complete analysis was made of the mineral elements present in this sample. In order to detect the minerals present in smallest trace quantities the sirup was concentrated by ashing in platinum at low temperature (250° C.). A few milligrams of ash sufficed for the spectrographic examination, the results of which are given below:

MINERAL ELEMENTS PRESENT IN A SUGAR CANE SIRUP ASH

Major	Minor	Trace	Small trace
Phosphorus	Calcium	Copper	Titanium
Silicon	Magnesium	Strontium	Barium
Potassium	Manganese	Tin	Vanadium
	Iron	Boron	Nickel
		Sodium	Chromium
		Aluminum	

At various later dates some six additional samples were received for analysis. Their copper contents were estimated by spectrographic comparison with the sirup mentioned above, and were reported as varying from 10 to 0.01 parts per million. Spectrum lines of the element cobalt were sought in each spectrogram taken, but were never detected. Therefore, it appears that cobalt could not have been present as plentifully as one part per million in any of the sirups. In answer to a request for information on the amounts of certain other elements present, estimated percentages of phosphorus, calcium, potassium, magnesium, iron, manganese and sodium were reported for one of the samples.

Toxic Elements:

In view of the use of compounds containing certain heavy inorganic elements in weed sprays, rat poisons and the like, it was felt that it would be well to have available a method for detecting small traces of these elements in plant and animal material. When the spectrograph is adjusted to photograph very deep into the ultraviolet ("Range III"), the most sensitive lines of arsenic, lead, thallium, mercury and phosphorus can be recorded simultaneously. Considerable experience was gained in the analysis, for these elements, of the ash of animal materials such as the livers, kidneys and intestines of horses, cows and dogs whose death was suspected of being due to inorganic poisons. (The various samples were kindly supplied by a local veterinarian, Dr. L. C. Moss.) Of course, before definite conclusions concerning inorganic element poisoning could be reached by such methods, comparisons would have to be made with the amounts of these elements present in the tissues of *normal* animals.

It might be remarked here that the ultimate sensitivity for the metalloid arsenic, using the most searching spectrographic methods available, was only 20 parts per million. This cannot compete with a specialized sensitive chemical technic such as the Gutzeit method.

Minor Elements in a Metallic Sample:

A good example of the rapidity of semi-quantitative spectrochemical methods is the recent analysis of a metallic sample. It was a "tin can" or metal container of the inside-lacquer-coated type manufactured locally for shipping pineapples and other acid fruits. These tins were being considered for use as pots for small plants in a minor element study. Therefore, it was desired to know the percentage of certain minor elements present in the material. The desired results, which are given below, were obtained in two or three hours:

ESTIMATED AMOUNTS (IN PER CENT) OF CERTAIN ELEMENTS PRESENT IN A PINEAPPLE TIN

Copper	Not over	0.1
Manganese	Approximately	0.1
Molybdenum	Approximately	0.01
Zinc	Less than	0.01
Boron	Less than	0.01

These low values indicated that the containers should be quite satisfactory for the purpose for which they were desired. In addition, the spectrograms taken in this

connection are on file and can be consulted if information on other elements is desired at some later date.

Nutrient Solutions:

An important type of agricultural research involves so-called "deficiency studies" in which plants are grown in culture solutions which are kept as free as possible from a particular element. The appearance or non-appearance of definite pathological or growth-failure symptoms indicates the essential or non-essential nature of that element to the plant being tested. Since the lower limits of spectrographic detection of the various elements are known (1), the spectrograph can be used to advantage in checking the purity of the nutrient solutions. Inadvertent addition of the element under test, in the chemicals and distilled water, and its subsequent accumulation in the nutrient solutions, can readily be detected. In fact the chemicals can easily be tested before use to see whether recrystallization is necessary.

Absorption Spectra:

The wave-length bands transmitted by various color filters can be checked by use of the small wave-length spectrometer in the spectroscopic laboratory, where a large selection of non-fading glass color filters is available. From these, P. L. Gow (4) has selected a filter which, when used in conjunction with the Klett colorimeter, increases the accuracy of the determination of nitrate nitrogen and potash by a factor of perhaps 5. Working with H. W. Brodie, Mr. Gow has selected a combination of filters that will transmit a wave-length band in the red which corresponds accurately to the well-known red absorption band of chlorophyll (5, 6). The use of such a filter in sunlight measurement should give data of more physiological significance than those secured when the sun's radiation in *all* wave lengths is measured.

Many solutions have selective absorption spectra which are characteristic of the molecules of the solute. There are a number of good examples of this for the case of large organic molecules. Vitamin A, in ethyl alcohol solution, has a characteristic absorption band in the ultraviolet at 3280 angstroms, and this is the basis for one of the methods of assaying biological materials for this vitamin. A simplified method of vitamin A determination by the spectrograph was worked out recently at the University of Hawaii by Martin E. Nelson and the writer (7). It was found that the vitamin A content of fish liver oils could be determined with an average error of 5 to 10 per cent. This method is of course much faster than the standard biological feeding method. Also, the spectrograph differentiates between vitamin A and its precursor, beta-carotene, which has distinctive absorption bands in the green and blue regions of the spectrum. This power of distinction was illustrated in the case of opihi, the Hawaiian limpet, which had been tested by feeding methods at the Hawaii Agricultural Experiment Station by C. D. Miller and R. C. Robbins and found to possess, on the moisture-free basis, about one-tenth the vitamin A activity expected of a good cod liver oil. The characteristic absorption band of vitamin A could not be detected in extracts of opihi, but the bands of beta-carotene were prominent.

The photometric equipment used in the study mentioned above was loaned from the spectroscopic laboratory of this Station. Since its return it has been considerably improved by Mr. Gow.

Ultraviolet Transmission of Glass and Celluloid:

The radiation of the sun, as received on the earth's surface, has a maximum in the yellow and drops quite sharply to zero on the short wave length side near 3000 angstroms. Glass and certain other "transparent" materials transmit visible light, but become opaque in the range 3000 to 3500 angstroms in the near ultraviolet. Since it is desirable to have plants receive as much of the sun's light as possible, the transmission characteristics of materials to be used in the construction of greenhouses are of interest. The ultraviolet transmission of such materials can be tested readily by the spectrograph. A source is used which is strong in ultraviolet and in which the wave lengths are known; for example, the iron arc. The material under test is interposed between the light source and the spectrograph slit. Hence the photographed spectra terminate at the wave length for which the material becomes opaque. Actually the termination or "cut-off" is gradual, so several thicknesses of material can be used to intensify the effect, and show where the absorption commences. The results obtained when Mitscherlich greenhouse glass was tested are given in Table I.

TABLE I

ULTRAVIOLET TRANSMISSION LIMITS (IN ANGSTROMS) OF MITSCHERLICH GREENHOUSE GLASS

Specimen	Absorption begins	Transmission limit
New glass	3350	3100
Old glass	3500	3150

A heavy celluloid was under consideration for use in the construction of miniature "greenhouses" for individual plants. Since this material would be continually weathered by sun, rain and wind, it was tested over a period of three months, the strips of material being exposed to field conditions between tests. The results of the several observations made during this period are given graphically in Fig. 7. It is seen that there was a gradual loss of transparency in the ultraviolet, until at the end of three months some absorption was occurring in the visible region of the spectrum (that is, at wave lengths greater than 4000 angstroms). This absorption in the blue and violet accounts for the yellowish color of old, weathered celluloid. Such a material is opaque to the shorter rays from the sun and hence is unsuitable for use as a greenhouse covering.

ACKNOWLEDGMENTS

The various developments and results herein reported are not all those of the author alone, but many are due to the combined efforts of all who have worked in the spectroscopic laboratory. I refer chiefly to Mr. Gow, Assistant Chemist, and also, to a less extent, to P. E. Chu, Assistant Chemist. The spectrograph was first set up and used by the late C. W. Nesbitt. Discussions with A. S. Ayres relating

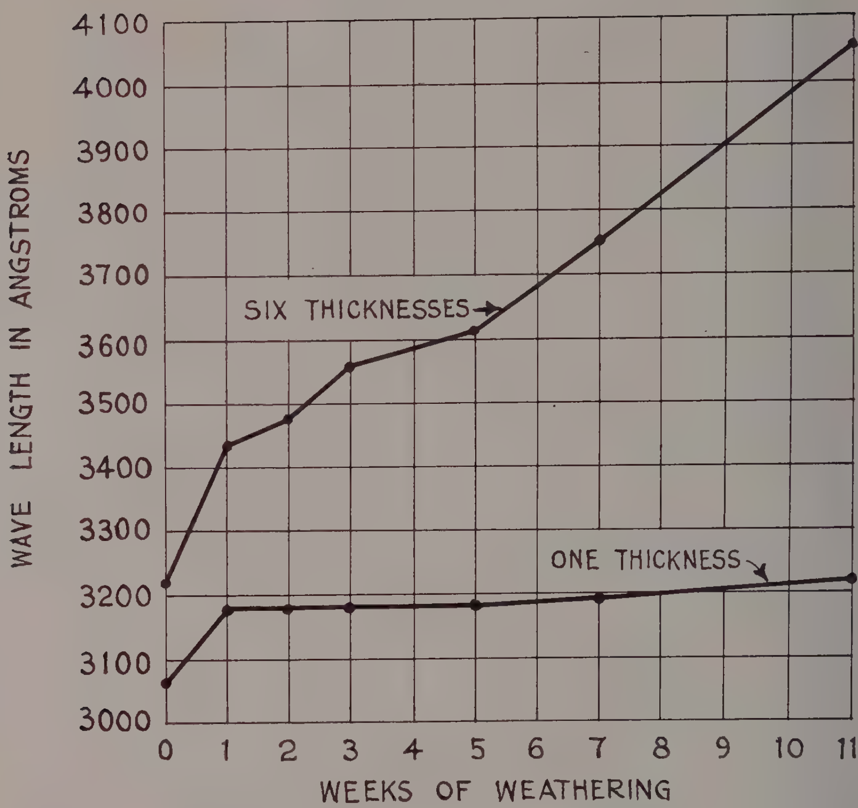


Fig. 7. Transmission limit (one thickness) and beginning of absorption (six thicknesses) plotted against time, for weathering celluloid.

to agricultural chemical analysis have been most helpful. The successful completion of this developmental program of spectrochemical analysis would not have been possible without the interest and the enthusiastic support of Dr. F. E. Hance.

Literature Cited

(1) Ballard, Stanley S., 1938. Occurrence of the minor elements in commercial fertilizers as determined spectrographically. The Hawaiian Planters' Record, 42: 185–195.

(2) ———————, 1939. Spectrographic analysis of three arthropods. Nature, 143: 979.

(3) ———————, and Gow, Paul L., 1939. Accessories for spectrochemical analysis. Journal of Applied Physics, 10: 556-557.

(4) Hance, Francis E., 1937. Experiment Station Committee Report, pages 85–86, Proceedings 57th Annual Meeting, H.S.P.A.

(5) ———————, 1938. Experiment Station Committee Report, page 84, Proceedings 58th Annual Meeting, H.S.P.A.

(6) ———————, 1939. Experiment Station Committee Report, pages 90–92, Proceedings 59th Annual Meeting, H.S.P.A.

(7) Nelson, Martin E., and Ballard, Stanley S., 1940. Spectrographic determination of vitamin A. Physical Review, 57: 253A.

Irrigation Interval Control as an Aid in Lowering Production Costs

By J. A. Swezey and H. A. Wadsworth

For more than sixty years the Hawaiian sugar industry has invested money in irrigation enterprises. Ditches have been constructed to convey water from streams remote from the land under cultivation. Mountains have been tunneled to recover water from underground reservoirs. Costly pumps have been installed to supplement inadequate gravity supplies and to boost water to fertile slopes above the ditch line.

More than $300 has been expended to provide water for the average irrigated acre in Hawaii. Corresponding figures for Continental United States indicate that it has required nine times as much money to irrigate the average acre in Hawaii as has been required for a similar area in the nineteen Western States in which irrigation is supposed to be essential for crop production.

The Background

Planters have long been aware of the necessity of providing for the economic use of such costly irrigation resources. Investigations of the water cost of sugar cane and the effect of varying intervals between applications of water upon cane and sugar yields have been almost continuous since the original work of Schuyler and Allardt in 1889. The results of the earlier works have been summarized by Alexander (1). Later studies, particularly those involving more recent conception of plant and water relationships, have been reviewed by Shaw (4) and Shaw and Swezey (5). In one of these papers (5) the following statements were made as a fair expression of the concepts of the relationships between irrigation, soil moisture and cane growth which had resulted from experience elsewhere as well as from the long series of experiments and observations with the sugar cane plant.

Modern Conception of Plant and Water Relations in Hawaiian Soils:

1. Studies in Hawaii as early as 1896 recognized the variation in the power of Hawaiian soils to hold moisture. Many local investigators have noted that soils can hold only a definite amount of water and that additional water was wasted by deep penetration.
2. The limited movement of water from moist to dry soil by capillarity and the limited extent of lateral moisture movement in the soil was early recognized by investigators in Hawaii.
3. Experiments conducted from 1916 to 1926 on plantations of the Territory approached the conception of a wilting percentage or lower limit of available soil moisture. In general, however, the wilting percentage was apparently considered as a function of the cane plant rather than of the soil, subject to seasonal variation and to the age and variety of the cane.
4. Studies by the Experiment Station, H.S.P.A., since 1928 have attempted to determine basic relationships between the cane plant, plantation cane land soils, and irrigation water with the view of obtaining methods by which commercial irrigation could be guided more economically and skillfully.

5. Investigations conducted in the laboratory, in pot tests, in large tanks, and in the field have established certain fundamental relationships which may be well considered and used in commercial irrigation:

- *a.* Cane growth is independent of the soil moisture content for some time after irrigation, the growth rate being influenced only by season, age of cane, and by cultural operations other than irrigation.
- *b.* Cane growth is severely affected, and may cease entirely, when the soil moisture content reaches a critical value which is dependent upon the physical nature of the soil rather than upon the type of plant or the season.
- *c.* The cane plant does not exhibit external symptoms of wilt for several days after the critical limit of available soil moisture for growth has been reached. The appearance of the plant or of the surface of the soil are not safe standards on which to base the need for irrigation water.
- *d.* The normal rate of cane growth is resumed quickly after irrigation water is applied unless the period of inadequate soil moisture is sufficient to damage the physical structure of the plant.
- *e.* The cane plant continues to transpire considerable quantities of water even when the soil moisture content is too low to promote active growth.

6. In an attempt to develop a single-value soil constant which could be used to classify soils on the basis of their moisture-holding characteristics, a simple laboratory determination called the moisture equivalent was examined critically:

- *a.* The moisture equivalent appears to be the best available method for the rapid classification of the physical nature of Hawaiian soils.
- *b.* The maximum field capacity is equal to 1.1 times the value of the moisture equivalent on practically all soils examined.
- *c.* A high correlation was found between the moisture equivalent and the permanent wilting percentage, or lower limit of available soil moisture. The moisture equivalent of a soil divided by 1.25 is roughly equal to the wilting percentage of that soil. However, enough exceptions and departures from this generality exist to warrant caution in the use of the moisture equivalent for precise determinations of the lower limit of soil water available for cane growth.

Although these principles seemed sound in view of the precautions used in the experimental work involved as well as because of their similarity with results secured elsewhere, it was thought wise to subject them to a field trial upon plantation scale. An elaborate study on the land of the Waialua Agricultural Company, Ltd., under the authority of a cooperative agreement between that plantation and the Experiment Station, H.S.P.A., demonstrated the basic soundness of these general conceptions. The results of this investigation, which continued from 1933 to 1936, were published in 1937 (5).

Economic Factors in Interval Control

During the early studies at Waipio (4) and later at Waialua, it had been frequently noted that cane growth, as measured by the observations upon the last visible ligule, was retarded when the soil moisture supporting that cane was allowed to fall below the permanent wilting percentage. Since there was no evidence in these studies that cane which had suffered in this way grew abnormally fast after water had been applied, it seemed evident that a significant and irrecoverable loss of cane would be associated with each period of soil moisture deficiency. Several hypothetical cases were suggested in the report of the Waialua observations (5). These indicated that the potential yields were reduced by from 1.81 to 10.42 tons of cane per acre as a result of intermittent periods of soil moisture deficit. A reason-

able basis of estimation was used; the variations in the reported potential cane loss were attributed to variations in the total number of days of depressed growth which was experienced by the several fields. Since it is often assumed that a reduction of yield, in terms of tons-cane-per-acre is associated with a corresponding reduction in the yield of sugar-per-acre it would necessarily follow that maximum sugar yields could only be obtained if irrigations were so timed that no periods of soil moisture deficiency or so-called "idle days" were permitted.

It will be recalled that the late Dr. U. K. Das questioned the validity of this assumption. This worker suggested that the delay of irrigations might depress the rate of cane growth during periods of soil moisture deficiency but at the same time induce periods in which physiological activity would be extended toward a greater manufacture of sugar.

Although it seemed clear from the first Waialua investigations that greatest yields of cane, and presumably of sugar, could be obtained by irrigating at such a frequency that the soil moisture would never be allowed to fall below the permanent wilting percentage, it was by no means evident that a sugar yield of maximum economic value was secured by this practice. It seemed that the possible losses of cane and sugar resulting from lengthening the irrigation intervals might be offset, or more than offset, by savings in the cost of the water used and the cost of the labor required to apply it.

A continuation of the cooperative agreement with Waialua Agricultural Company, Ltd., permitted the inauguration of an elaborate experiment in the hope that some evidence might be secured as to the costs and values involved. The purpose of this paper is to report the results secured from this experiment.

The outline of the experiment required:

(*a*) Ten replications, or more than the minimum for "Grade A" status.

(*b*) Plots to be of sufficient size to minimize border effect from irrigations throughout the crop and to minimize any errors in cane weights at harvest due to changes in harvesting methods.

(*c*) A site with a reasonably general slope, as free as possible from gullies, and with soil uniform in moisture-holding capacity and other characteristics.

(*d*) A site convenient to a constantly available source of water, to assure an irregularly required supply without undue interference with plantation routine.

(*e*) A site in a plant field, or with cane not older than a second ratoon, to insure good condition of furrows and good stand of cane.

(*f*) Generally dry weather conditions as judged from past records.

(*g*) The following treatment plan:
Treatment *A*—Irrigated to provide 8 "idle days"* of growth prior to each irrigation.

* The term "idle days" is used to express the time between the end of normal vegetative growth and the next irrigation. Thus if all available evidence indicates that the normal growth of a field was retarded on May 10, because of soil moisture deficiency and was not irrigated until May 20, the field would have suffered 10 "idle days."

Treatment *B*—Irrigated to provide 4 "idle days" of growth prior to each irrigation.

Treatment *C*—Irrigated to provide 0 "idle days" of growth throughout the crop.

(*h*) All other operations in the experimental area to be conducted according to the plantation practice in the field in which the experiment would be located.

The Experimental Layout

Field Kemoo 1-B at Waialua Agricultural Company was selected as fulfilling the requirements outlined. The experiment was installed as soon as the field was ratooned, which was early in June 1937, and given the number 138-I. The site was a 20-acre portion of the field which was in the herring-bone system of irrigation, except for a small piece served by straight long-lines. The average length of lines between flumes was about 350 feet. It was possible to lay out 30 plots of approximately ½ acre each, in a block arrangement suitable for interpretation of results by the "analysis of variance" (Fig. 1). Irrigation water was admitted to the furrows in both the herring-bone and the straight long-line areas by individual slide gates which facilitated accurate control of the water.

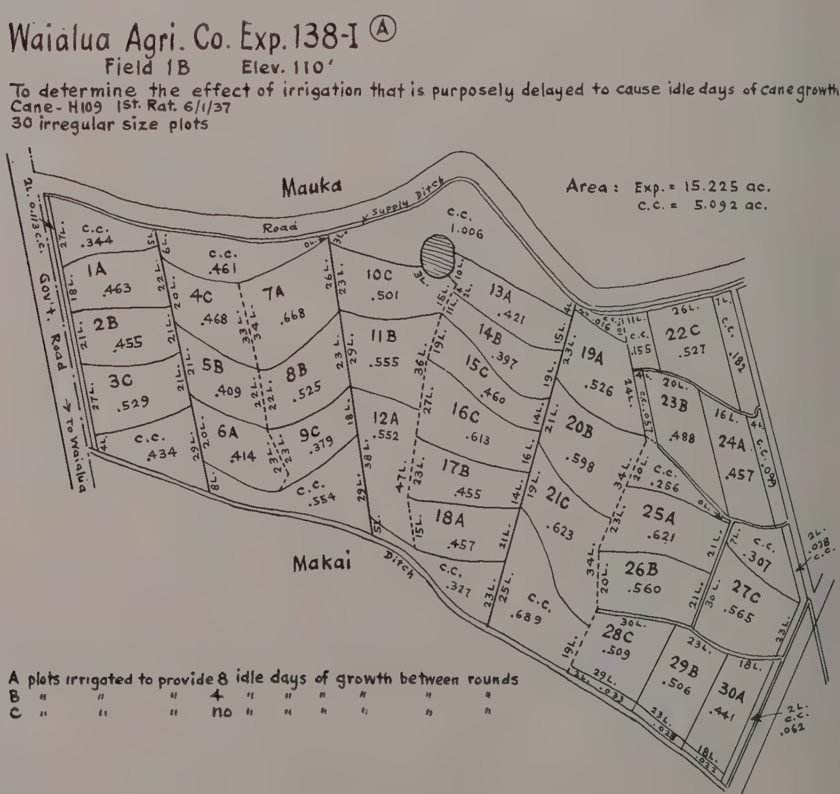
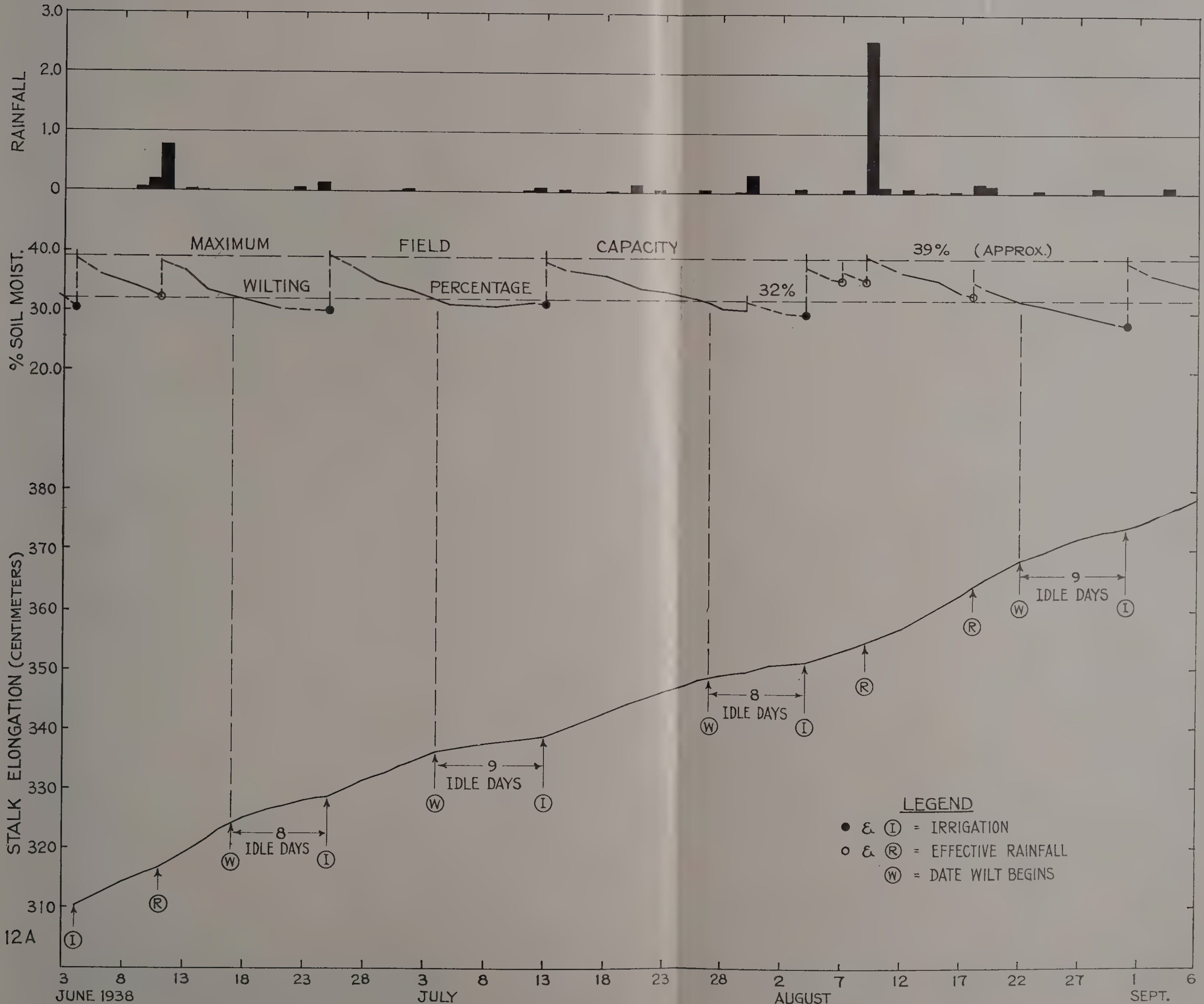
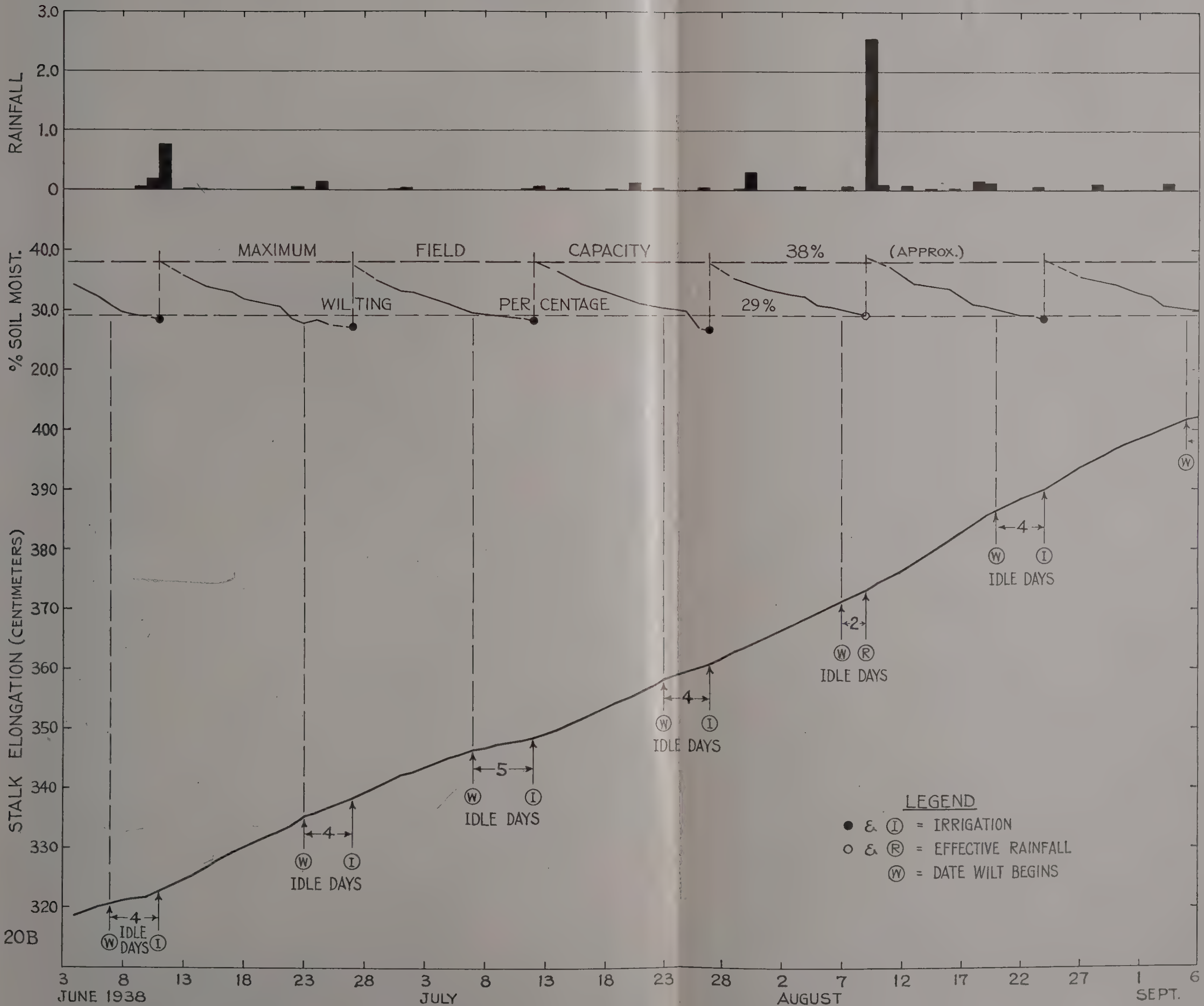


Fig. 1



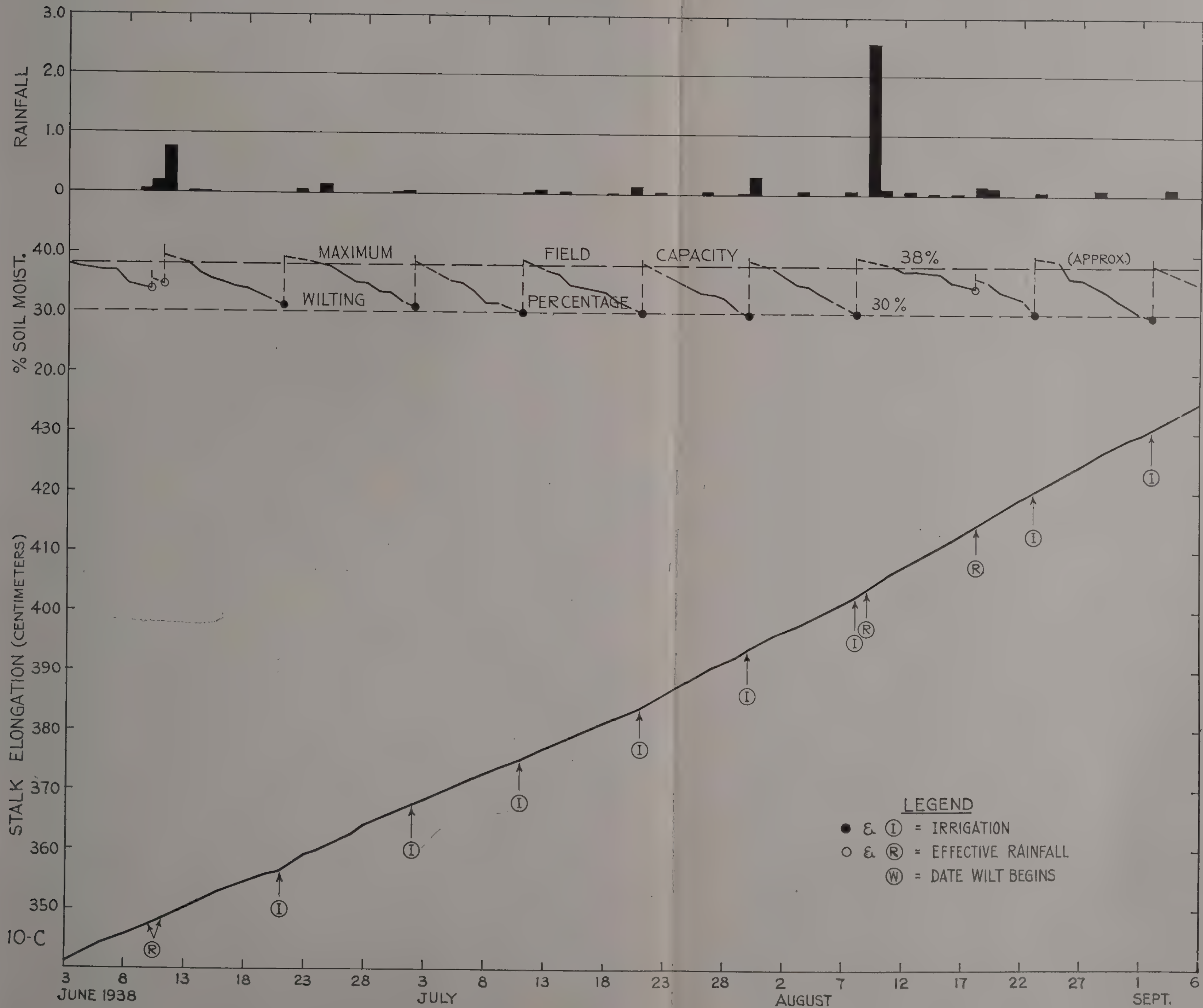
RAINFALL
3.0
2.0
1.0
0
% SOIL MOIST.
40.0
30.0
20.0
MAXIMUM FIELD CAPACITY 39% (APPROX.)
WILTING PERCENTAGE 32%
STALK ELONGATION (CENTIMETERS)
380
370
360
350
340
330
320
310
12A
8 IDLE DAYS
9 IDLE DAYS
8 IDLE DAYS
9 IDLE DAYS
LEGEND
● & Ⓘ = IRRIGATION
○ & Ⓡ = EFFECTIVE RAINFALL
Ⓦ = DATE WILT BEGINS
3 8 13 18 23 28 3 8 13 18 23 28 2 7 12 17 22 27 1 6
JUNE 1938
JULY
AUGUST
SEPT.

Fig. 2


RAINFALL
3.0
2.0
1.0
0
% SOIL MOIST.
40.0
30.0
20.0
MAXIMUM FIELD CAPACITY 38% (APPROX.)
WILTING PER CENTAGE 29%
STALK ELONGATION (CENTIMETERS)
400
390
380
370
360
350
340
330
320
4 IDLE DAYS
4 IDLE DAYS
5 IDLE DAYS
4 IDLE DAYS
2 IDLE DAYS
4 IDLE DAYS
LEGEND
● & Ⓘ = IRRIGATION
○ & Ⓡ = EFFECTIVE RAINFALL
Ⓦ = DATE WILT BEGINS
3 8 13 18 23 28 3 8 13 18 23 28 2 7 12 17 22 27 1 6
JUNE 1938
JULY
AUGUST
SEPT.

20B

Fig. 3



RAINFALL
3.0
2.0
1.0
0
% SOIL MOIST.
40.0
30.0
20.0
MAXIMUM
FIELD
CAPACITY
38%
(APPROX.)
WILTING
PERCENTAGE
30 %
STALK ELONGATION (CENTIMETERS)
430
420
410
400
390
380
370
360
350
10-C
3
8
13
18
23
28
3
8
13
18
23
28
2
7
12
17
22
27
1
6
JUNE 1938
JULY
AUGUST
SEPT.
LEGEND
● & Ⓘ = IRRIGATION
○ & Ⓡ = EFFECTIVE RAINFALL
Ⓦ = DATE WILT BEGINS

Fig. 4

An observation station for observing cane growth and soil moisture was established in each plot during the first week in August 1937. The techniques for soil moisture sampling and for growth measurements were similar to those described in the 1937 report (5). A moisture-equivalent survey of the experimental area indicated acceptable uniformity in moisture-holding capacity throughout the 20 acres.

Preliminary studies of cane growth and soil moisture depletion indicated the approximate permanent wilting percentages of the soils at these observation stations. Practically all stalks throughout the experimental area had formed millable joints by the middle of September. By this date the plants were three months old. Differential treatments were begun immediately. The first idle time was imposed prior to the tenth irrigation. It was considered necessary to allow approximately 7 idle days in the plots of Treatment *C* at this time as a final check on the wilting percentages involved. Thereafter, it was possible to avoid idle time in this treatment.

Control of irrigation intervals in the experimental plots was accomplished by maintaining a continuous, graphic record of the average stalk elongations and the observed soil moistures. Each plot was administered individually, according to its specified treatment. Irrigations were ordered for the *A* and *B* treatments when the required time had passed since the beginning of a period of soil moisture deficiency, as indicated by all available evidence. Figs. 2, 3, and 4 show how the control indicated the proper dates for irrigation in a typical plot of each treatment. In the *A* and *B* treatments, the date on which idle time commenced could be determined with considerable confidence by a study of the soil moisture and stalk elongation curves. The date for irrigation was determined by adding the specified number of idle days to the date of inception of soil moisture deficiency. Between October and February, it was somewhat difficult to decide whether stalk elongation might be reduced by winter influences or by a soil moisture deficiency. This was particularly evident in the *B* plots which were irrigated only 4 days after the wilt commenced. For this reason it was necessary to extend the *B* treatment to 6 idle days, and the *A* treatment to 12 idle days during the winter months.

Control of irrigations in the *C* plots was somewhat more difficult than in the *A* and *B* plots. As has been indicated irrigations in this treatment were to be so timed that depletion of soil moisture below the permanent wilting percentage would be prevented. At the same time it was necessary to avoid irrigating prematurely if the results were to be interpreted in terms of the cost of sugar, water and labor. Control involved making daily observations of soil moisture. A study of these observations permitted, and often required, setting the date of an irrigation as late as the night before it was due. Cane growth observations served as a check on the irrigation control and as an indication of the crop's progress. They were of no value in forecasting the dates for irrigations. It is gratifying to report that the control of irrigations in the *C* treatment, as well as in the other two, was maintained throughout the crop in exact accord with the original specifications.

Although the relative dryness of the area chosen was one of the factors considered in its selection, natural precipitation had to be allowed for in the operation which has been described. A general conception of the effect of rain upon cane

growth was developed during earlier cooperative experiments at Waialua. The following statement appeared in the report of this work (5):

> A study of the soil moisture and rainfall records of the Waialua investigation indicates that rainfall under 0.4- to 0.5-inch is ineffective as an irrigation. At best it appears that 0.25- to 0.50-inch of rain is equivalent to but one day of interval. Although light showers from 0.10- to 0.40-inch appeared to have maintained partially normal growth during periods of inadequate soil moisture, they did not replenish the soil reservoir perceptibly.
>
> *Soil Moisture Program Preferable to Formula in Accounting for Rain:* We would hesitate to offer a formula for expressing the effective value of rainfall based on the data obtained at Waialua. Such an equation would be so general as to have little use in specific cases or under localized conditions elsewhere. If all factors were taken into account in formulating the equation, it would then become too cumbersome for easy, universal application.
>
> We prefer to suggest that a program of soil moisture sampling will provide information as to soil moisture contents both before and after rainfall as well as the general prevailing trend of moisture depletion. With no deliberate attempt to evaluate the rainfall, a judicious interpretation of the soil moisture data will provide an index of the proper date for the next irrigation.

This concept of rainfall was applied, when necessary, in operating Experiment 138-I. In all, a precipitation of 60.92 inches was received by the crop; most of this rain fell during the winter months. The rest fell for the most part in small ineffective showers. Some of these amounted from ½ to 2 inches, but they were relatively infrequent and were far from annoying. As a matter of fact, these showers helped to make the control more interesting, and to prevent it from becoming too conventional. In general, it was unnecessary to attempt an evaluation of rainfall in controlling irrigations since the detailed sampling program provided an excellent history of soil moisture conditions before and after each rainfall.

Rainfall was observed each morning before the start of the day's work. If there had been sufficient rainfall to warrant delay according to the method of evaluation suggested above, irrigations which might have been scheduled for the morning would be withheld until soil moisture samples gave evidence as to the actual effect of the rain.

Treatment averages for stalk elongation for each plot from the start of crop to the first day of each month were computed from the daily record of the measured dewlap movement. These averages, which include all plots in a single treatment, appear in Table I and are shown graphically in Fig. 5. The data in either form show the growth history of the crop under the conditions imposed by the three differential treatments. Fig. 5 also shows the accumulated idle days which resulted from the differential treatments (Table II). A schedule showing the idle days impressed upon each plot during the course of experimental irrigation is given in Table III.

It is apparent that any evaluation of the results, in terms of cost of producing a ton of sugar, would involve a knowledge of the amount of water used in each of the three treatments as well as the number of man-days spent in irrigating. Consequently, a water-measuring program was begun which in the end provided useful information. It was found impractical to measure water to every plot. The number of man-days spent in irrigating each plot was carefully recorded. Other

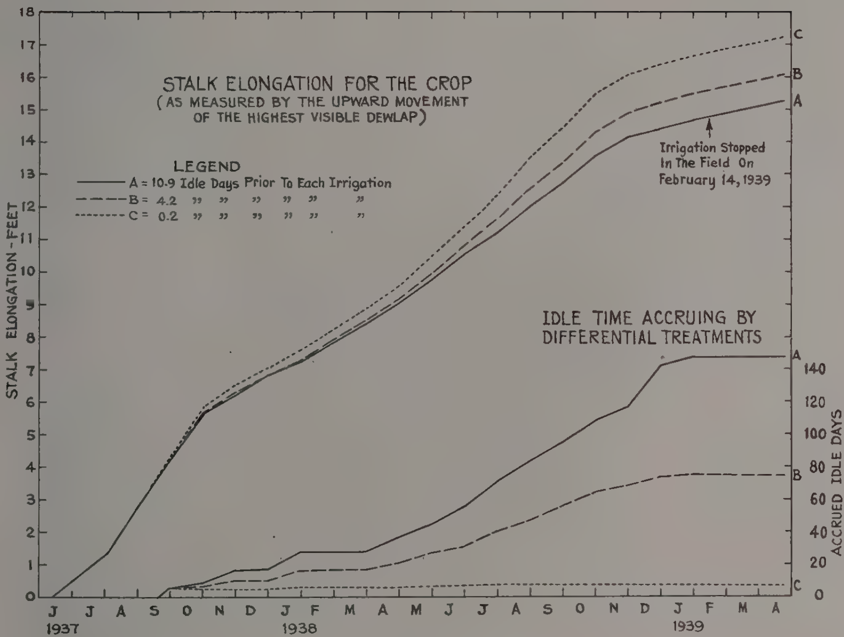


Fig. 5

operations, such as weeding and fertilizing, were similar on all plots of the experiment and need no consideration in this analysis.

It was possible to maintain a record of the number of man-days used each day for irrigating, as well as number of acres irrigated. Weekly figures of man-days per acre were tabulated. A second table of individual plot irrigations (arranged by irrigation numbers) was prepared which showed the man-days per acre for each irrigation. The labor cost for a given irrigation was taken as the figure for the week in which the irrigation occurred. The accumulated sum of average man-days per acre for each treatment as of the first of each month is listed in Table IV, and shown graphically in Fig. 6.

A Parshall flume was installed in the flume supplying water to Plots 1*A*, 6*A*, 2*B*, 5*B*, 3*C*, and 4*C*. These plots constituted two out of the 10 blocks of replications in the experiment. It was economically impossible to install water-measuring flumes in the water sources of the other 8 blocks. Consequently, the information obtained from the measurements of water to the plots in the two blocks was applied to all of the plots of similar treatment.

Measurements of water applied to each of the six plots under the Parshall flume were not made for each irrigation. They were taken, however, as many times as was convenient. The measurements obtained in terms of acre-inches per acre were tabulated by plots according to irrigation number. When the crop was completed, these amounts of water were plotted, by treatments, against their corresponding irrigation numbers. All values from the two measured plots of each treatment were used. This method produced a curve which may be taken as fairly representative of all the plots in that particular treatment. The plotted points were some-

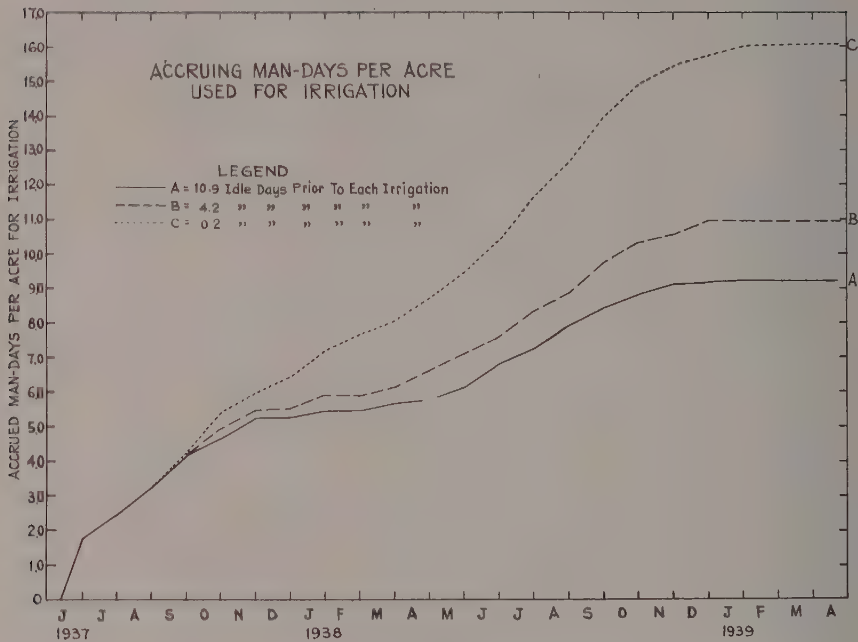


Fig. 6

what scattered, but trend curves for each treatment could be drawn which satisfied all observations with acceptable precision. These curves are shown in Figs. 7, 8, and 9. They show an increasing depth of application with advancing crop age as might be expected. Moreover, there is evidence of an increasing difference in depths of application on the *A* plots as compared with those of the *B* series and of the *B* plots over those of the *C* series. No convincing explanation can be offered for this observation at present.

From these curves it was possible to secure a measure of the depth of application for each irrigation, although in many cases no direct observations were available. These tabulations were made by individual plots. Treatment averages were computed for the total depth of water applied as of the last of each month. This monthly progress in the use of water in terms of millions of gallons per acre is shown in Table V and Fig. 10.

Table VI and Fig. 11 give a consolidated summary of the number of idle days imposed upon each treatment, together with the amounts of water and irrigation labor used by each treatment.

The fertilization of the experiment was the same as that applied to the surrounding field. The schedule of fertilization appears below:

POUNDS PER ACRE

Plots	No. of plots	Appl. 1 7/9/37 A.S.	Appl. 2 7/21/37 APa	Appl. 3 7/22/37 M.P.	Appl. 4 8/8/37 A.S.	Appl. 5 9/29/37 M.P.	Appl. 6 3/1/38 A.S.	N	Totals P_2O_5	K_2O
All	30	300	300	175	450	101	150	217	147	166

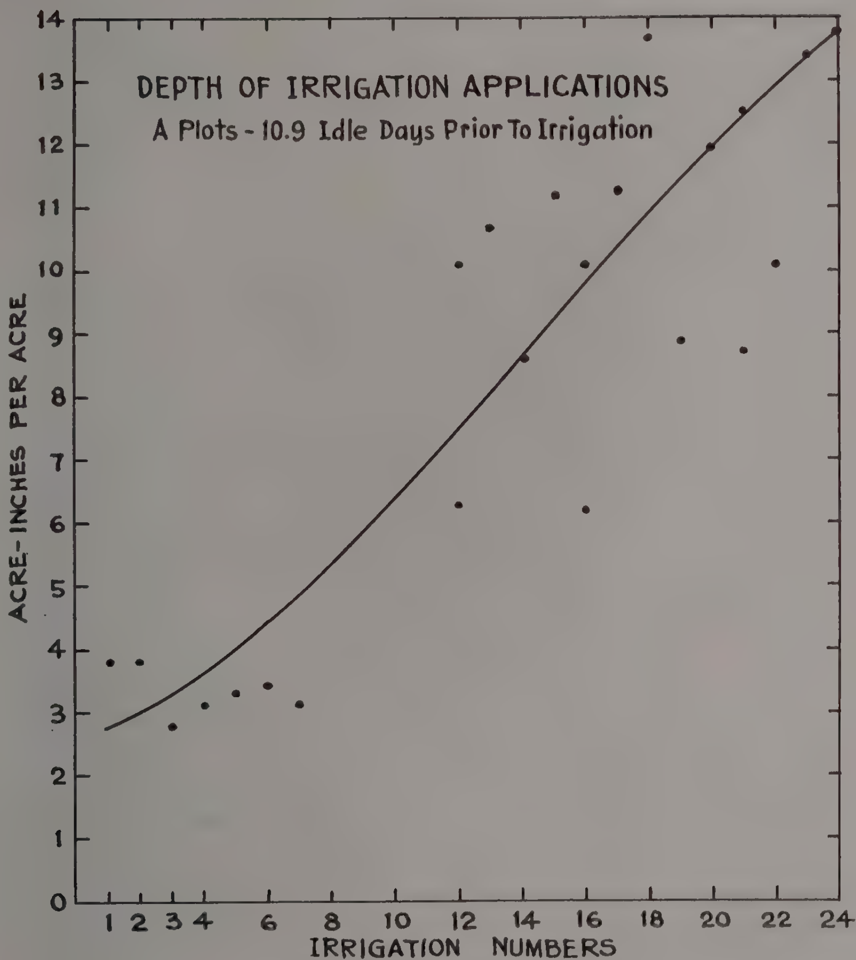


Fig. 7

Fertilizer analyses:

APa = 10.8% N, 49% P_2O_5
M.P. = 60% K_2O
A.S. = 20.5% N

Method and point of application of fertilizer:

Nos. 1, 2, 4—by hand in the cane line
Nos. 3, 5, 6—by water in the cane line

Irrigation was ended in Field Kemoo 1-*B*, including the plots in the present experiment, on February 15, 1939, for the purpose of drying-off before harvesting. All plots commenced their drying-off period at approximately the maximum field capacity.

Harvesting operations were commenced on April 24 in the experimental area.

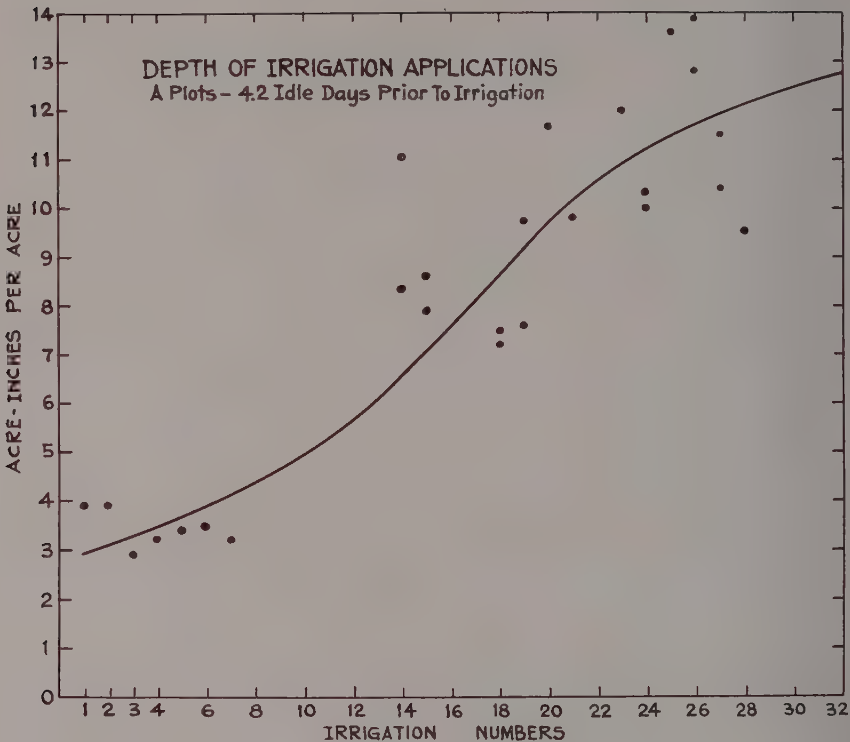

DEPTH OF IRRIGATION APPLICATIONS
A Plots – 4.2 Idle Days Prior To Irrigation
ACRE-INCHES PER ACRE
IRRIGATION NUMBERS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1 2 3 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

Fig. 8

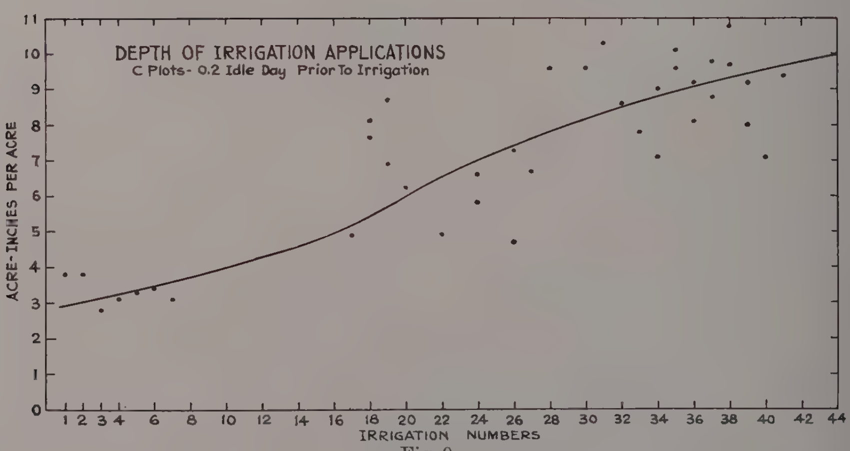

DEPTH OF IRRIGATION APPLICATIONS
C Plots - 0.2 Idle Day Prior To Irrigation
ACRE-INCHES PER ACRE
IRRIGATION NUMBERS
0
1
2
3
4
5
6
7
8
9
10
11
1 2 3 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

Fig. 9

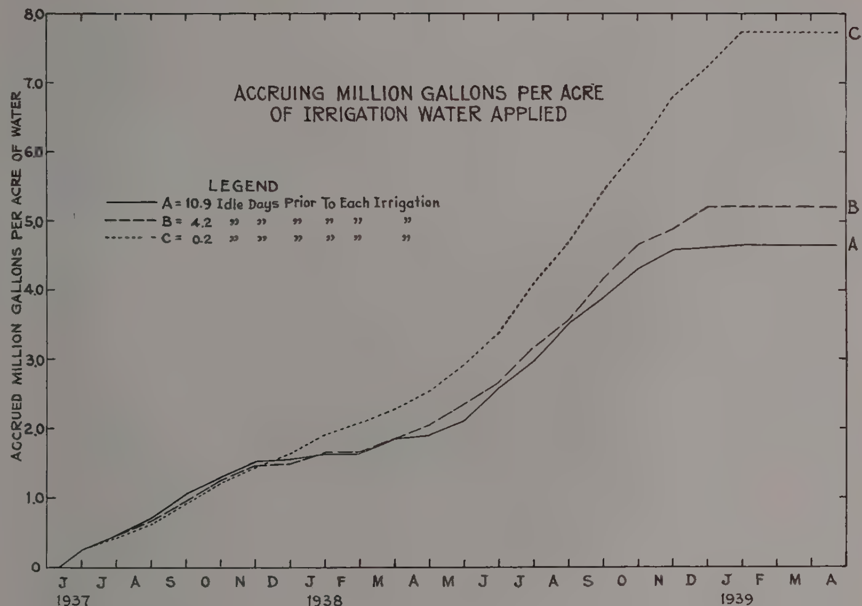


Fig. 10

Cutting required two days, and all cane had been milled by April 27. All plot boundaries were opened ahead of the regular cutting gangs. Extreme care was taken to insure perfect segregation of cane by plots. The cane was hand-cut and topped, hand-piled, and machine loaded. This insured clean cane which required no washing at the mill. Cars were switched in the yard into a minimum number of groups of cars all of which came from a single plot. Because of this procedure, the mill engineer was able to eliminate wash water on the carrier. All the experimental cane was ground dry. The juice qualities obtained were, therefore, unaffected by external water.

A single running crusher-juice sample was obtained for analysis, from each group of cars from a given plot. Results from the analyses of these juice samples were averaged to secure the best value for the plot. The yield data appear in Table VII, and are shown graphically in Fig. 12. The extremely low standard errors of these results may be attributed to a combination of accurate irrigation control throughout the crop, the uniformity of soil and cultural practices, and to the degree of care exercised in the harvesting of the experiment. Table VIII, as well as Fig. 13, gives a summary of the cost of producing sugar in the three treatments in terms of millions of gallons of water and man-days of labor.

An appreciation of the weather experienced by the crop may be secured from Table IX which tabulates rainfall records and temperature data in terms of day-degrees by months.

Discussion

An inspection of the results given in Tables VI, VII and VIII indicates that the *A* treatment with almost 150 idle days in its history, during which normal vege-

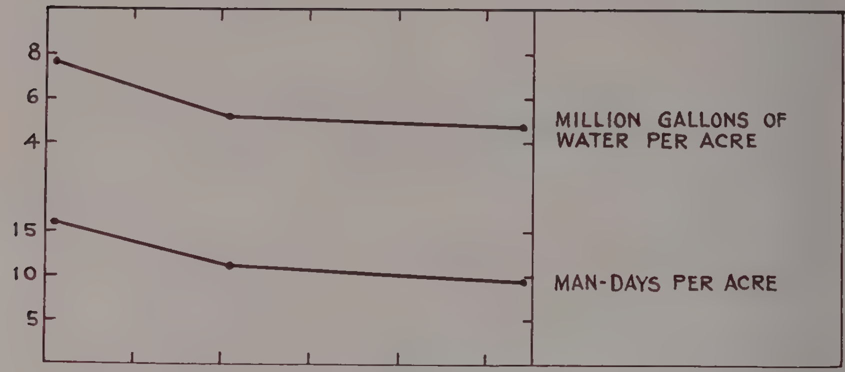


Fig. 11

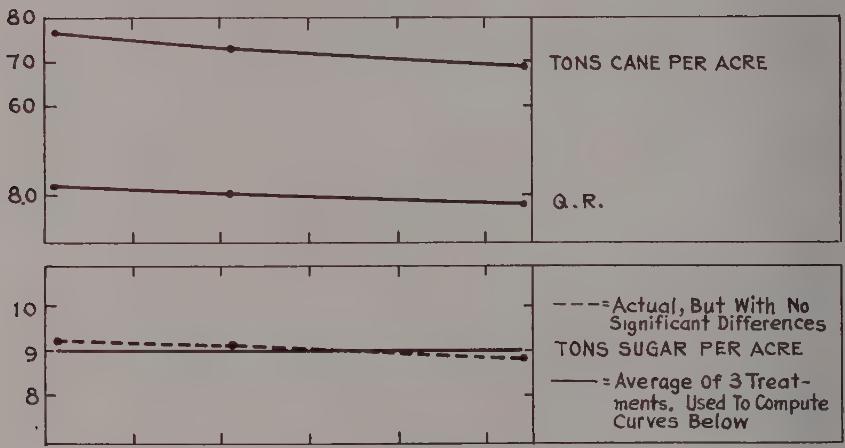


Fig. 12

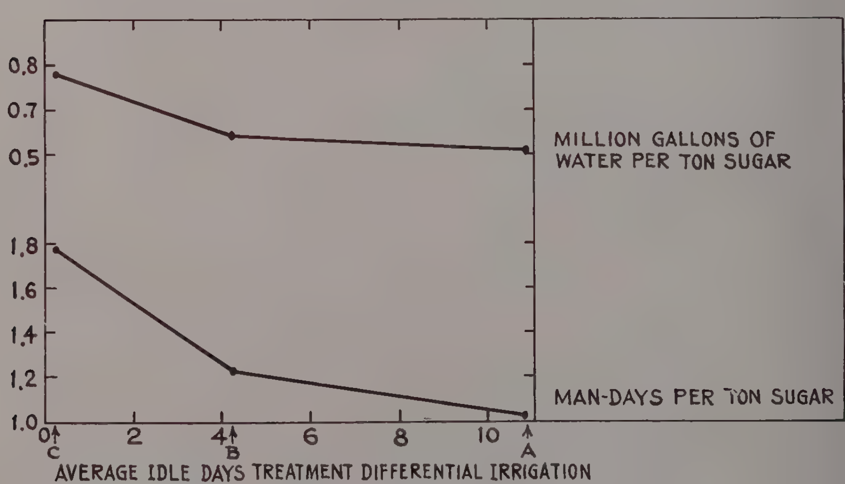


Fig. 13

tative growth was handicapped, produced as much sugar per acre as was produced when the crop was kept in full vegetative vigor throughout the entire period. Since there is a definite increase in the number of tons of cane per acre produced in the *C* treatment over the *B*, and the *B* over the *A*, it must follow that the sugar content in the cane increases as the number of idle days increases. Such conclusion is borne out by the figures for "Quality Ratio" and "Yield % Cane" in Table VII.

Greater significance is to be found in a consideration of the cost figures which are involved. Nine tons of sugar per acre were produced in each of the treatments. But 7.73 million gallons of water and 16.07 man-days were required to produce that amount of sugar under one treatment and only 4.66 million gallons of water and 9.22 man-days under another. With water and labor costs as they are it would appear that considerable economy in sugar production might be effected by deliberately forcing the plant to reduce its vegetative vigor at frequent intervals during its growth.

The following hypothetical case is suggested to illustrate these possible savings. The experiment reported above was located in a field which is about average for the district as far as crop producing capacity is concerned. We may assume that it may be taken as representative for a hypothetical plantation. Since there was no difference in sugar yield, in terms of tons of sugar per acre, between the plots receiving 10.9 idle days and 0.2 idle day per differential irrigation, the gross income for the annual crop of the plantation would be the same in either case. The difference in the annual cost of irrigation would therefore be an indication of the preferred policy with respect to irrigation practice. As has been indicated fertilization and other field operations were similar in both treatments of the experiment and may be assumed as identical in our hypothetical case. If we tabulate the necessary cost data, a comparative cost sheet like that given below is secured. It is assumed that Plantation X produces an annual crop of 35,000 tons of sugar. Water is valued at $12.00 per million gallons for illustrative purposes; irrigation labor is charged at $2.00 per man-day.

COMPARATIVE COST DATA FOR A PLANTATION OPERATING UNDER TWO DIFFERENT POLICIES WITH RESPECT TO IRRIGATION INTERVAL

	Policy *A*	Policy *C*	
Differential irrigation treatment, per irrigation.	10.9 idle days	0.2 idle day	
Total man-days per ton of sugar, for irrigating..	1.03	1.79	
Million gallons of water, per ton of sugar......	0.52	0.86	
Cost of labor per ton of sugar at $2.00 per man-day	$2.06	$3.58	
Cost of water per ton of sugar at $12.00 per million gallons	$6.24	$10.32	
Total cost of irrigating, dollars per ton of sugar	$8.30	$13.90	
Annual crop, tons of sugar....................	35,000	35,000	
Total irrigation cost, per year.................	$290,500.00	$486,500.00	
Difference, in favor of Policy *A*...............			$196,000.00

It is probable that most irrigated plantations follow a schedule that is between that called Policy *A* and Policy *C*. The suggested possibility of saving money through irrigation interval control should justify some consideration however.

The experiment reported above proved to be inadequate in that none of the treatments produced a reduction of yield through an over extension of irrigation interval. One cannot ascertain from Fig. 11, which has but three points on the curve of labor and water expenditures as related to tons of sugar produced, whether or not the period of 10.9 days of idle time, before each irrigation was the maximum that could be allowed without loss. It is perfectly possible that a longer period of idle time would result in an increase in the cost of sugar produced due to a significant decrease in yield. This possibility is now being investigated in a similar experiment at the Waipio Substation. In the current experiment there are four differential treatments in place of three. It may therefore cover the entire scope of idle time that results in decreasing irrigation costs per ton of sugar produced and include an additional interval which results in decreased yields and increased unit costs.

From the results of the Waialua experiment it would appear that some of the terminology suggested in previous papers on irrigation control might be misleading. For example, the use of the phrase "Proper Interval" is questionable if we use it to designate the time required to reduce the soil moisture content from maximum field capacity to the permanent wilting percentage. The following terms and definitions are suggested:

Depletion Interval: The interval from the date of irrigation until such time as the soil is depleted to the permanent wilting percentage. This interval may be expressed in whatever units of time or weather conditions are desired.

Proper Interval: The interval that will produce sugar at the least cost per ton. Again the unit may be either one of time or weather conditions.

It is conceivable that these two intervals might be numerically equal, under some conditions. From the present work, however, it is to be expected that the "Proper Interval" may be considerably greater than the "Depletion Interval."

Field experiments of this sort do not lend themselves well to a study of the causes that brought about the end result. All that can be said is that the treatments of delayed irrigations which were imposed upon the crop seemed to lead to a more efficient synthesis and accumulation of sugar. Apparently it did the crop good to dry out. This thought has frequently been expressed by practical and observant cane growers.

It will be recalled that Das (2) reached an analogous conclusion from his study on the nitrogen nutrition of sugar cane. Although he was not directly interested in soil moisture relationships, he concluded that the degree of hydration of the tissues of the plant was of great importance in regulating sugar synthesis. Das presented considerable evidence in support of the assumption that carbohydrates elaborated through photosynthesis are liable to be stored as sucrose if the hydration of the tissue is low, but will be carried through continued processes of elaboration if hydration is high. A natural conclusion would be that a cane plant growing continuously in a high degree of hydration would yield much green weight but little sugar.

Whether it is possible to impose variations in hydration of the sort meant by

Das, by manipulation of soil moisture content, may well be questioned. If the hydration suggested by Das can be measured by observations upon the Brix of the juice in a growing stick, we have considerable evidence (6) that this hydration suffers significant diurnal variation even at high soil moisture percentages. We have but little information upon the juice quality if samples for this determination are taken after the moisture in the soil supporting the plant has fallen to the permanent wilting percentage or below it.

Although the results reported are spectacular and promising, the fact remains that they are still empirical. We only know what the end result is from a particular treatment. We do not know how that end was reached. Nor can we be sure that the same treatment in another location and under different environmental conditions would give the same result. Considerable physiological work is necessary if we hope to reason from cause to effect and to state, with confidence, what the result will be from such irrigation treatments as these, in untried environments.

It can hardly be denied that water is essential for the synthesis of sugar. And yet the plants in the *A* treatment, where water according to our best thought must have been only slowly available during the idle days in its history, produced as much sugar as in the *C* treatment where every effort was made to keep the plants well supplied. It is simple to imagine the existence of water-storage tissues which become important in the plant when soil moisture deficiencies appear in the crop history. We may speculate still further on the luxury consumption of water by the plant when moisture is readily available, and the economical use of water which is slowly released from our hypothetical water-storage tissues when scarcity threatens. Hartt (3) reports a greater diurnal range of moisture content in the leaf sheath than in any other part of the plant studied. Preliminary, and not convincing observations upon the lengths of the leaf sheaths, produced under the several treatments in the Waialua experiment, indicate that the sheaths produced in the *A* treatment, where water deficit was most pronounced were shorter and much more variable in length than those from the plants which enjoyed continuously high soil moisture contents. It is possible, as has been suggested, that the leaf sheaths are the water-storage tissues; the length of a sheath when it falls from the plant may be determined, to some extent at least, by the demand made upon it while it was gaining maturity. If so, the trash from a field which has experienced a continuously high soil moisture content should be heavier than the trash from one which has suffered occasional periods of deficiency. There is some evidence, too, that the leaf spindle, crowning the growing point, hidden away in the green top, continues to grow at its usual rate for some time after the conventional "last visible ligule" gives evidence of soil moisture deficiency by a reduction in its normal rate of growth. Can this be taken as evidence of the fact that every effort is made to keep the top growing even if water must be withdrawn from tissues below? And if so can observations on the leaf spindle, in place of the ligule, be used in the estimation of the plant's need for water? And can it be said that the drought-resistant varieties of cane are better equipped with such hypothetical water-storage tissues than other varieties?

Such questions are much more easily asked than answered. And yet such answers are needed for the rational explanation of the findings that have been reported.

Acknowledgment

The writers wish to acknowledge with sincere appreciation, the cooperation of J. H. Midkiff, Manager of Waialua Agricultural Co., Ltd., and his staff. The Irrigation, Automotive, Harvesting, Railroad and Milling Departments have been particularly helpful. Without the helpful cooperation of the personnel of the Kemoo Division and of the fine young men who were assigned to aid in the field and laboratory determinations the work would have been impossible. Messrs. R. J. Borden, F. C. Denison, and others of the Experiment Station Staff were generously helpful with their encouragement, advice and assistance.

Literature Cited

(1) Alexander, W. P., 1923. The irrigation of sugar cane in Hawaii. Expt. Stn., H.S.P.A.
(2) Das, U. K., 1936. Nitrogen nutrition of sugar cane. Plant Phys. 11: 251-317.
(3) Hartt, Constance E., 1936. Further notes on water and cane ripening. The Hawaiian Planters' Record, 40: 355-381.
(4) Shaw, H. R., 1930. Studies on the response of cane growth to moisture. Rept. of Association of Hawaiian Sugar Technologists, 127-147.
(5) ————, and Swezey, J. A., 1937. Scientific irrigation management. The Hawaiian Planters' Record, 41: 199-279.
(6) Wadsworth, H. A., 1936. Some aspects of the internal water economy of the sugar cane plant. The Hawaiian Planters' Record, 40: 21-33.

TABLE I
PROGRESS OF STALK ELONGATION
(as measured by dewlap movement)
AVERAGE ELONGATION IN FEET

Date	*A*	*B*	*C*	Date	*A*	*B*	*C*
6/11/37........	....	....	....	7/1/38........	10.53	10.81	11.43
8/4/37........	1.37	1.37	1.37	8/1/38........	11.19	11.63	12.41
9/1/37........	2.79	2.79	2.79	9/1/38........	12.02	12.59	13.52
10/1/37........	4.27	4.30	4.33	10/1/38........	12.74	13.38	14.42
11/1/37........	5.65	5.68	5.86	11/1/38........	13.57	14.30	15.47
12/1/37........	6.25	6.34	6.59	12/1/38........	14.18	14.89	16.06
1/1/38........	6.84	6.85	7.10	1/1/39........	14.40	15.22	16.39
2/1/38........	7.25	7.29	7.63	2/1/39........	14.68	15.50	16.67
3/1/38........	7.87	7.94	8.25	3/1/39........	14.89	15.71	16.88
4/1/38........	8.43	8.52	8.88	4/1/39........	15.11	15.93	17.10
5/1/38........	9.04	9.18	9.61	4/24/39........	15.28	16.10	17.27
6/1/38........	9.75	9.95	10.50				

TABLE II
ACCUMULATION OF IDLE TIME
AVERAGE IDLE DAYS TO DATE

Date	*A*	*B*	*C*	Date	*A*	*B*	*C*
6/11/37.........	....	....	...	7/1/38.........	55.9	31.3	6.6
8/4/37.........	....	....	...	8/1/38.........	71.7	40.8	7.1
9/1/37.........	....	....	...	9/1/38.........	84.0	47.6	7.1
10/1/37.........	6.2	4.6	4.7	10/1/38.........	95.4	56.2	7.1
11/1/37.........	9.2	6.3	5.3	11/1/38.........	108.4	64.9	7.1
12/1/37.........	17.2	10.1	5.3	12/1/38.........	117.2	68.8	7.1
1/1/38.........	17.2	10.1	5.3	1/1/39.........	142.7	74.1	7.1
2/1/38.........	28.1	16.6	6.1	2/1/39.........	148.2	75.5	7.1
3/1/38.........	28.1	16.6	6.1	3/1/39.........	148.2	75.5	7.1
4/1/38.........	28.1	16.6	6.1	4/1/39.........	148.2	75.5	7.1
5/1/38.........	37.1	20.8	6.1	4/24/39.........	148.2	75.5	7.1
6/1/38.........	45.3	26.9	6.5				

TABLE III
ANALYSIS OF AVERAGE IDLE DAYS PER DIFFERENTIAL IRRIGATION

Plot No.	No. irrigations prior to differentials	Total No. of irrigations	No. of differential irrigations	Total No. of idle days	Idle days per differential irrigation
		TREATMENT *A*			
1	9	22	13	151	11.6
6	9	24	15	162	10.8
7	9	22	13	150	11.5
12	9	23	14	160	11.4
13	9	24	15	142	9.5
18	9	21	12	136	11.3
19	9	23	14	149	10.6
24	9	22	13	148	11.4
25	9	22	13	146	11.2
30	9	23	14	138	9.9
				Average	10.9
		TREATMENT *B*			
2	9	28	19	77	4.1
5	9	27	18	75	4.2
8	9	26	17	75	4.4
11	9	31	22	88	4.0
14	9	26	17	67	3.9
17	9	27	18	67	3.7
20	9	27	18	82	4.6
23	9	26	17	68	4.0
26	9	28	19	82	4.3
29	9	26	17	74	4.4
				Average	4.2
		TREATMENT *C*			
3	9	39	30	5	0.2
4	9	41	32	3	0.1
9	9	36	27	4	0.1
10	9	39	30	8	0.3
15	9	45	36	9	0.3
16	9	45	36	10	0.3
21	9	40	31	7	0.2
22	9	42	33	7	0.2
27	9	43	34	10	0.3
28	9	41	32	8	0.3
				Average	0.2

TABLE IV

ACCUMULATED MAN-DAYS PER ACRE USED FOR IRRIGATING

As of	Treatment *A* 10.9 idle days	Treatment *B* 4.2 idle days	Treatment *C* 0.2 idle day
6/11/37	.....	.....	.....
7/1/37	1.766	1.766	1.766
8/1/37	2.473	2.473	2.473
9/1/37	3.260	3.246	3.258
10/1/37	4.153	4.210	4.264
11/1/37	4.682	4.947	5.389
12/1/37	5.249	5.481	5.972
1/1/38	5.282	5.514	6.456
2/1/38	5.437	5.902	7.319
3/1/38	5.437	5.902	7.691
4/1/38	5.682	6.147	8.071
5/1/38	5.777	6.620	8.709
6/1/38	6.125	7.110	9.476
7/1/38	6.808	7.589	10.385
8/1/38	7.261	8.373	11.663
9/1/38	7.970	8.882	12.627
10/1/38	8.424	9.717	13.941
11/1/38	8.862	10.325	14.918
12/1/38	9.124	10.581	15.442
1/1/39	9.178	10.952	15.783
2/1/39	9.221	10.952	16.071
3/1/39	9.221	10.952	16.071
4/1/39	9.221	10.952	16.071
4/24/39	9.221	10.952	16.071

TABLE V

ACCUMULATED MILLION GALLONS OF WATER PER ACRE USED FOR IRRIGATING

As of	Treatment *A* 10.9 idle days	Treatment *B* 4.2 idle days	Treatment *C* 0.2 idle day
6/11/37	.....	.....	.....
7/1/37	0.244	0.253	0.246
8/1/37	0.451	0.447	0.423
9/1/37	0.702	0.664	0.615
10/1/37	1.058	0.963	0.876
11/1/37	1.311	1.263	1.242
12/1/37	1.530	1.471	1.453
1/1/38	1.552	1.489	1.638
2/1/38	1.639	1.665	1.923
3/1/38	1.639	1.665	2.077
4/1/38	1.862	1.854	2.288
5/1/38	1.910	2.057	2.549
6/1/38	2.124	2.347	2.918
7/1/38	2.625	2.654	3.393
8/1/38	2.970	3.175	4.094
9/1/38	3.523	3.570	4.686
10/1/38	3.888	4.166	5.427
11/1/38	4.300	4.666	6.050
12/1/38	4.584	4.889	6.795
1/1/39	4.619	5.214	7.224
2/1/39	4.656	5.214	7.727
3/1/39	4.656	5.214	7.727
4/1/39	4.656	5.214	7.727
4/24/39	4.656	5.214	7.727

TABLE VI

SUMMARY OF AVERAGE TOTAL DIFFERENTIAL IRRIGATION TREATMENTS

Treatment designation	Specified idle days per differential irrigation	Actual average idle days per differential irrigation	Total number of irrigations	Number of differential irrigations	Total labor for irrigating man-days per acre	Total water for irrigating millions of gallons per acre
A	Summer: 8 Winter: 12	10.9	22.6	13.6	9.22	4.66
B	Summer: 4 Winter: 6	4.2	27.2	18.2	10.95	5.21
C	Summer: 0 Winter: 0	0.2	41.1	32.1	16.07	7.73

Note: Remainder of Field Kemoo 1-B, irrigated by plantation routine, received a total of 37.2 irrigations.

TABLE VII

SUMMARY OF YIELDS AT HARVEST

Treatment designation	Average idle days per differential irrigation	T.C.A.*	Q.R.	Y%C	T.S.A.
A	10.9	69.0 ± 0.91	7.8	12.8 ± 0.08	8.8 ± 0.11
B	4.2	72.8 ± 1.53	8.0	12.5 ± 0.10	9.1 ± 0.21
C	0.2	75.6 ± 0.71	8.2	12.2 ± 0.14	9.2 ± 0.23

Analysis of variance: Indicated a definite effect of treatment on T.C.A. and Y%C, but no effect on T.S.A.

* Does not include field or main line pick-up cane, and is not adjusted for trash tare.

TABLE VIII

RELATION OF YIELDS TO DIFFERENTIAL TREATMENTS

Treatment designation	Average idle days per differential irrigation	Millions of gallons of water per ton cane	Man-days per ton cane	Millions of gallons of water per ton sugar*	Man-days per ton of sugar*
A	10.9	0.068	0.134	0.517	1.025
B	4.2	0.072	0.150	0.579	1.217
C	0.2	0.102	0.213	0.859	1.786

* Based on 9.0 T.S.A., the average yield of the three treatments, since there was no significant difference from the differential treatments.

TABLE IX

WEATHER DATA

Age at end of month		Rainfall: During month	Rainfall: Accum. at end of month	Day degrees: During month	Day degrees: Accum. at end of month
0.70	June 11-July 1, 1937..	.01	.01	263	263
1.70	July	1.54	1.55	386	649
2.70	August	1.57	3.12	383	1032
3.70	September	.51	3.63	428	1460
4.70	October	1.38	5.01	393	1853
5.70	November	1.51	6.52	327	2180
6.70	December	8.33	14.85	297	2477
7.70	January, 1938........	2.83	17.68	268	2745
8.70	February	12.36	30.04	291	3036
9.70	March	4.25	34.29	234	3270
10.70	April	2.49	36.78	283	3553
11.70	May	1.88	38.66	321	3874
12.70	June	1.57	40.23	388	4262
13.70	July	.67	40.90	423	4685
14.70	August	3.27	44.17	431	5116
15.70	September	.19	44.36	421	5537
16.70	October	.76	45.12	403	5940
17.70	November	1.15	46.27	286	6226
18.70	December	2.54	48.81	244	6470
19.70	January, 1939........	2.11	50.92	241	6711
20.70	February	3.53	54.45	240	6951
21.70	March	2.92	57.37	274	7225
22.50(Harvest)	April (up to 24th)....	3.55	60.92	164	7389

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD SEPTEMBER 16, 1939, TO DECEMBER 4, 1939

Date		Per pound	Per ton	Remarks
Sept.	16, 1939........	3.68¢	$73.60	Hawaiians.
"	21.............	3.60	72.00	Puerto Ricos.
"	25.............	3.65	73.00	Puerto Ricos.
"	28.............	3.6725	73.45	Puerto Ricos, 3.67, 3.675.
Oct.	13.............	3.60	72.00	Philippines.
"	16.............	3.50	70.00	Puerto Ricos.
"	18.............	3.40	68.00	Puerto Ricos.
"	21.............	3.30	66.00	Puerto Ricos.
"	24.............	3.28	65.60	Puerto Ricos, 3.25; Cubas, 3.31.
"	28.............	3.10	62.00	Puerto Ricos.
"	31.............	2.90	58.00	Philippines.
Nov.	1.............	2.95	59.00	Puerto Ricos.
"	10.............	3.05	61.00	Philippines.
"	20.............	3.00	60.00	Puerto Ricos.
"	27.............	3.21	64.20	Cubas.
"	28.............	2.95	59.00	Puerto Ricos.
Dec.	4.............	2.98	59.60	Philippines.

TABLE OF CONTENTS